THE UNIVERSITY OF ALBERTA

A COMPARISON OF TECHNIQUES OF ELECTRICAL MUSCLE STIMULATION CONCURRENT WITH ISOMETRIC EXERCISE ON THE DEVELOPMENT OF QUADRICEPS STRENGTH

by

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A THESIS

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Dedication

My Mother and Father

- who have encouraged me to pick a goal in life and persevere to reach that success, no matter how difficult the task.

ABSTRACT

The purpose of the study was three-fold. A comparison of the effects of training with electrical muscle stimulation concurrent with isometric exercise, and isometric exercise alone was illustrated. A comparison of the monopolar and bipolar electrical stimulation techniques was illustrated. Lastly, an observation of the concept of specificity of training was given.

Twenty-one male volunteers, ranging in age from 18 to 35 years, participated. None had a recent history of significant pathology to the knee joint or surrounding musculature of the right lower limb. Subjects were pre and post-tested on girth measurements, isokinetic measurements, and isometric strength measurements. The control group maintained a pattern of normal daily living. The isometric exercise group and two electrical muscle stimulation groups trained daily, five days each week, for a duration of six weeks. All training was performed with the right knee placed over a standard knee board fixed at an angle of -30° knee extension. The leg was isometrically restrained at the ankle and a restraining strap was placed across the hips in an attempt to prevent excessive movement. The 10:50:10 method was used during each training session. The monopolar and bipolar electrical muscle stimulation concurrent with isometric exercise groups differed with electrode plate size and placement.

The statistical analysis used was a two-way MANOVA with repeated measures. The Helmert contrast and pairwise contrasts were the post-hoc tests used. The MANOVA interaction effects were used to indicate where significant differences occurred.

Within the limitations of the study, the following conclusions appear justified:

1. Electrical muscle stimulation concurrent with isometric exercise was more effective towards enhancing quadriceps strength over a control group which did no training.

2. Electrical muscle stimulation concurrent with isometric exercise was as effective as but no more effective than isometric exercise alone, for enhancing quadriceps strength.

3. The two electrical muscle stimulation techniques concurrent with isometric exercise produced similar effects.

4. Girth increments were observed to be indicative of the electrical muscle stimulation technique used.

5. The electrical muscle stimulation concurrent with isometric exercise groups demonstrated minimal changes in dynamic strength.

6. Muscular power was affected more by the monopolar, rather than the bipolar, electrical stimulation technique concurrent with isometric exercise.

7. Muscular endurance was affected more by the

bipolar, rather than the monopolar, electrical stimulation technique concurrent with isometric exercise.

8. Considering pre-treatment values and increments with training, the monopolar electrical stimulation technique concurrent with isometric exercise was more effective for enhancing isometric strength at -15° and -30° knee extension.

9. Bipolar electrical stimulation concurrent with isometric exercise was more effective for enhancing isometric strength at -45° and -60° knee extension.

10. Specificity of training at an angle of -30° knee extension was observed.

Training with isometric exercise alone, or electrical muscle stimulation concurrent with isometric exercise enhances quadriceps strength. As a consequence of a low frequency faradic current being used to train healthy, innervated quadriceps muscle, significant differences were lacking to conclusively determine the more effective technique of electrical muscle stimulation.

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STATEMENT OF THE PROBLEM

Introduction

> "Theory often follows practice. It is indeed fascinating and intriguing to discover why things work."
>
> H. Art Quinney, April 1980

The quote by H.A. Quinney would serve to exemplify the use of electrical muscle stimulation in the rehabilitation of musculoskeletal injuries.

The concepts of utilizing electrical current in healing of visceral pathology, or inducing a muscle contraction by passing an electrical current through it is not new (33,54,60). The earliest documented use of an electrical charge applied to the human body for curing disease was the shocks of the torpedo, an electric fish, used for the treatment of gout, as described by the Greek physician AEtius (54).

In the intervening centuries from AEtius to the present, technological advances have been considerable, with extensive use of electrical muscle stimulation in the treatment of denervated muscle, internal disorders, states of paralysis, neuropathies, spasticity, and various other forms of non-musculoskeletal pathology (7,33,54,55). Electrical stimulation of musculoskeletal pathology has been concentrated on peripheral nerve injuries, paralysis,

muscle re-education and prevention of post-operative thrombosis (7,33,54).

Until recently, those individuals involved in the paramedical field of rehabilitation have accepted and utilized without question the techniques, rationale and methods of electrical muscle stimulation application set down decades ago. Lately, the era of "scientific inquisition" has pervaded the paramedical field, with respect to electrical muscle stimulation. Those involved with the treatment and prevention of injuries to sports participants have begun to ask questions and focus their attention on the potential benefits to be accrued from the use of electrical muscle stimulation. The motivating factor is one of minimizing "down time" due to injury in an attempt to return the participant to his or her sport as soon as possible, but within the limits of safety.

The paramedical field has begun to employ simple deductive logic. It has been documented in the literature (33,55) that electrical muscle stimulation, particularly the faradic waveform, most closely approximates the physiological responses of a normal voluntary muscle contraction. Muscular exercise strengthens muscle, and increases the volume of tendons and ligaments enhancing their tensile strength (2). Blood supply to the active muscles, and removal of waste products is enhanced (2). The metabolic rate is increased, as is the demand for oxygenation and nutrients (2). Venous and lymphatic return is enhanced,

and changes in the enzymatic composition of muscle occur (2).

If there are certain physiological effects derived from muscular exercise, and if the faradic waveform of electrical muscle stimulation most closely approximates that of a normal voluntary muscle contraction, it would seem logical that similar benefits must be acquired through the utilization of electrical muscle stimulation.

If electrical muscle stimulation of denervated and paralyzed states of muscle can minimize atrophic changes, facilitate circulation, prevent adhesion formation, and enhance venous and lymphatic return (50,55,60), then the effects of electrical muscle stimulation on normal innervated muscle might be as great. The fact that normal innervated muscle is characterized by different physiological properties than is denervated muscle necessitates the use of the faradic waveform for stimulation, as opposed to the galvanic waveform for denervated muscle.

With spreading interest involving electrical muscle stimulation, many authors (9,11,14,15,22,61,63) have applied the faradic waveform to traumatized joints and their surrounding musculature. Several studies (9,11,15) have focused on the response of various post-operative knee pathologies to electrical muscle stimulation as measured in terms of muscular enzymatic changes, strength retention, muscular atrophy, and length of overall rehabilitation. Generally, the degree of success has varied but has been

favorable towards minimization of strength and girth loss in muscle. Definitive comparison of all documented studies is difficult as a result of extraneous variables in pathology and management, and the lack of standardization of technique.

Until such time as controlled research involving standardization of techniques, application, and resultant effects of faradic stimulation is documented, use of the faradic current may waste valuable rehabilitation time for both the injured athlete and the therapist. Although the altruism 'Only God and time can heal.' pervades rehabilitation of musculoskeletal trauma, therapists are morally obliged to do everything within their power to optimize the conditions for healing.

The Problem

Past studies (9,11,15,28,61) have reported the benefits of electrical muscle stimulation in the rehabilitation of skeletal muscle, whether post-operative or post-trauma. If documentation of method or technique is given, the variations become obvious. As a direct consequence of these diverse techniques, comparison of study results is virtually impossible. Additionally, isometric exercise, which has been the forerunner and conventional form of exercise therapy, is being pushed aside without adequate evidence to suggest its lack of effectiveness.

Thus, the problem under investigation was three-fold.

1. To investigate and compare the two proposed treatment programs of electrical muscle stimulation concurrent with isometric exercise, and a program of isometric exercise alone.

2. To investigate and compare monopolar and bipolar techniques of electrical muscle stimulation.

3. To investigate changes in specified physiological parameters at a variety of joint angles following a treatment regime of training at one specified angle.

Significance of the Study

Owing to its anatomic characteristics, vulnerable position, necessity of unimpeded mobility and inability to be adequately protected by equipment, and the many stresses often placed upon it, the knee is a frequently injured joint. The axiom that 'a joint is only as good as its surrounding musculature' is especially relevant for the knee joint where particular concern is given to the quadriceps muscle group because of its strong protective quality.

After injury, the knee joint may reach a state of complete repair of all its structural components. However, if the quadriceps and other musculature responsible for controlling the knee joint have been neglected, which may cause atrophy and lack of tonicity, the knee joint remains sub-normal with respect to adequate function.

Greater concern in rehabilitation must be focused on

the muscular development surrounding the knee joint. This point is of major concern when dealing with an injured athlete, who is anxous to return to active participation as soon as possible. "Down time" resulting from injury becomes a prominent factor of concern in the rehabilitation process.

Until recently, the sole means of regaining lost muscle strength and integrity post-injury with or without surgical intervention and immobilization utilized isometric exercise. Rehabilitation normally required 6 to 8 weeks before the injured tissues had reached the stage whereby progressive resistance exercises (PRE) could be started with no detrimental effects to the patello-femoral articulation. The aim of any musculoskeletal rehabilitation program is progression to the stage of PRE as soon as possible, but safely.

Several authors (11,15,21) have suggested that utilization of faradic muscle stimulation given during rehabilitation would progress the injured athlete to the stage of PRE in less time than the conventional 6 to 8 weeks. Although levels of success vary with the studies cited and cross-comparisons are unrealistic as the result of the considerable variations in techniques employed, the fact that rehabilitation time was reduced is indeed of clinical importance.

It should be re-iterated that although the ability to heal is not humanly possible, the potential to optimize

the conditions for healing is within the therapists' field. The question arises as to whether therapists are in fact following the concept of optimization when they insist on utilizing untried and untested techniques of electrical muscle stimulation.

Members of the medical and paramedical fields recognize the absence of standardization of electrical muscle stimulation techniques but continue to overlook this pitfall. For example, Godfrey et al. (15) stated:

> "... The next step would appear to be a study examining whether a combination of isometric exercise plus tetanizing stimulation would lead to greater strength increase in the quadriceps muscle, following weakness caused by trauma or surgery."

Godfrey et al. (15) were premature in their conclusions. A great many variables are uncontrollable when performing research on traumatized skeletal muscle, such as the severity of the injury or nature of the surgery.

The study performed by Johnson et al. (22) set the justification for the present study.

> "... The effects of electrical stimulation on muscle tissue have been recognized for more than a century..., little is known about the standardization or efficiency of technique."

When controlled research concerning techniques of electrical muscle stimulation and the subsequent effects on normal healthy innervated muscle where fewer variables exist is completed, optimization of the conditions for healing can be maximized.

Delimitations

1. All subjects were male student volunteers, between 18 to 35 years of age.

2. The right lower limb was tested and treated for all subjects in all groups.

3. None of the subjects who participated in the study had a significant history of lower limb pathology.

4. The study involved daily treatment sessions, five days each week for a duration of six weeks.

5. The rectangular waveform was utilized for all subjects in the monopolar and bipolar stimulation groups, for every treatment session.

Limitations

1. The subject's constraint of "normal daily living" was beyond the control of the investigation.

2. The concept of performance of a maximal isometric effort was individually perceived. Each subject may have had their own psychological and physiological convictions.

3. The extraneous variables of psychological tension, diet, and sleep which could have influenced the health of tissues and muscular strength were not controlled.

4. The psychological frame of mind that the subject adopted during the testing and treatment sessions as related to pain tolerance of electrical muscle stimulation, and to the concept and output of maximal voluntary contraction was uncontrolled.

5. The intensity of the electrical muscle stimulation current was subjectively determined by the subject's individual tolerance, in each treatment session.

6. The results of the investigation shall be extrapolated as to the possible ramifications for use on injured muscle.

Definition of Terms

1. Low Frequency Current: A current characterized by a voltage or tension that is constantly changing and is quite low, effecting a sudden change of ionic concentration in the tissues affected, a stimulation effect of motor and sensory nerves, a rate of oscillation or frequency below 1,000 cycles per second (cps), a capability to cause a tetanic muscular contraction, and applied topically (54).

2. Electrical Muscle Stimulation (EMS): An artificial stimulation of a muscle or motor nerve effecting a minimum twitch, produced by the passage of an electrical current applied topically over the nerve plexus, nerve trunk, motor point, or muscle belly, and causing a contraction of the muscle adequately stimulated (55,60).

3. Faradism (F): A form of electrical stimulation, consisting of a rapid rise and fall of unidirectional current impulses, characterized by a rectangular, square, sawtooth, trapezoidal, or triangular waveform, a frequency of 50 to 100 cps, pulsed or non-pulsed, and current pulse widths of 1.0 to 2.0 milliseconds (msec). The current is

capable of inducing tetany in a skeletal muscle (54,60).

4. "10:50:10": Notation refers to a 10-second "maximal" isometric muscle contraction concurrent with faradic current of maximal intensity for a subject, followed by a 50-second rest interval. The routine is repeated until ten consecutive contractions have been performed (27).

5. Electrode Plate: A plate containing an alloy of zinc, lead and aluminum, varies in size, is malleable, and has a plastic-encased connecting lead attached to it (54, 55).

6. Active Electrode Plate: A plate referred to as the cathode or negative terminal, placed distal to the anode, and placed over the motor point or muscle belly of the muscle being stimulated (33,60,66).

7. Dispersive Electrode Plate: A plate referred to as the anode or positive terminal, placed proximal to the cathode, and placed over the nerve plexus, nerve trunk, area of little subcutaneous tissue, or muscle belly of the muscle being stimulated (33,60,66).

8. Monopolar Technique: A technique characterized by electrode plates of unequal size. The smaller active electrode is placed distally over the motor point of the muscle. The larger dispersive electrode is placed proximally over the appropriate nerve trunk, nerve plexus, or area of little muscle tissue. The technique has the ability to stimulate more muscles and deeper muscles (55,60, 66).

9. <u>Bipolar Technique</u>: A technique characterized by electrode plates of equal size, placed over the muscle belly, or functionally related muscle group. The active electrode is placed distal to the dispersive electrode. The technique has the ability to stimulate throughout the course of a muscle with an even distribution of current, and will affect superficial muscles only (33,35).

CHAPTER II

REVIEW OF LITERATURE

Introduction

A multitude of publications describing electrical muscle stimulation research is available in North America. Many of these existing publications have focused on denervated human muscle, animal muscle tissue, or histochemical and biochemical tissue studies. Practical data investigating the effects of EMS on normal innervated muscle is scant.

To date, studies on EMS are often reported in a vague manner, causing replication and cross-comparison of the results to be prevented. For example, some studies utilized static exercise whereas other studies utilized dynamic exercise. Results from studies utilizing healthy and diseased muscle have been compared. Thus, comparison of quantitative measurements in the literature to date becomes difficult.

However, EMS is still being utilized throughout various stages of rehabilitation to supplement established programs of static and dynamic exercise.

Techniques of Electrical Muscle Stimulation

The literature contains a variety of techniques and methods of electrical stimulation with minimal consistency and rationale. Thus, comparison of studies is difficult

and any conclusive statements must be accepted with caution.

Bouman and Shaffer (4) discussing the physiological characteristics of denervated human muscle also included methods of electrode application. Skin resistance was minimized and impedance to current flow reduced if the area to be stimulated was clean and warm. Electrodes could be applied using the monopolar method whereby the smaller active electrode was placed over the motor point and the larger dispersive electrode placed elsewhere, proximally. The bipolar method utilized equal sized electrodes applied to include the entire length of the muscle belly. Bipolar technique gave a local distribution of current and within certain limits did not spread to other muscle groups. Milner and Quanbury (41) stated that for monopolar stimulation of innervated muscle, motor points will vary slightly with individuals, but the relative position followed a reasonably fixed pattern. The current must meet three conditions in order to stimulate an excitable tissue:

a) The current must be of sufficient intensity.

b) The current must be of sufficient time duration.

c) The current must reach maximum intensity with an adequate speed of rise.

(4)

If a muscle is stimulated through its nerve, a slight increase in current will give a marked increase in muscle contraction. If the muscle is stimulated directly, an increase in contraction strength from an increase in current

intensity will be much less marked because the muscle possesses an increased excitation range. Bouman and Shaffer also stated that it was possible to increase muscle contraction strength if a human muscle was loaded maximally such that all muscle fibres are contracting and the stimulation current impulse rate was as high as could be tolerated.

Kramer (34) stated that the Russian technique was difficult to interpret as a consequence of incomplete technique and current description. Russian technique as described by Kots is thought to use a surging current and the format of 10-seconds of stimulation followed by a 50-second rest interval, repeated ten times. Strength gains overall were similar whether the treatments were carried out on alternate days or on five consecutive days followed by two days of rest. The key factors were stated as being the total number of stimulation treatments, and an adequate rest period following each treatment. Optimal strength gains occurred with 20 to 25 treatments and were reported to be increments of 30% to 40%.

Garrett et al. (13), 1980, used a machine of variable voltage with a frequency of 50 pulses per second to study the effects of EMS on quadriceps strength. Within each pulse was a sinusoidal waveform of high frequency. The EMS group and the exercise group were trained according to an established protocol daily, five days per week, for a duration of five weeks. There was no indication of the protocol. All groups were strength tested on a weekly

basis.

Kots (27) described the rationale behind the 10:50:10 routine which is presently used in many varied forms. Kots stated that EMS was useful in the treatment of soft tissue and hard tissue injuries, to increase strength of healthy muscles, to produce better results than traditional exercise routines alone, and to isolate particular muscles for individual sports activity. The current must be strong enough to give a maximal contraction of the muscle stimulated and the current must produce a low pain intensity or no pain, if the current is to be effective.

Two types of electrical stimulation methods exist. Bipolar or direct stimulation involves placing one electrode at either end of the muscle. Bipolar stimulation primarily affects the superficial muscles. Monopolar or indirect stimulation consists of placing one electrode on the muscle to be stimulated, and the remaining electrode over the appropriate nerve root. Monopolar stimulation affects not only the superficial muscles, but also the deeper muscles supplied by the nerve.

According to Kots, the maximum contraction of a muscle in a sample group of athletes lasts 10 to 15 seconds, and as a result of this the actual stimulation is 10 seconds. If there is no maximal contraction, it is pointless to use EMS. Using a 10-second contraction, Kots investigated various rest periods of 10, 20, 30, 40 and 50 seconds between the stimulations. For the intervals of 40

and 50 seconds, the amplitude of contraction from the second cycle did not differ from the first cycle, as happened with rest intervals of 10, 20 and 30 seconds. Kots then compared a 10-second stimulation with rest intervals of 40 and 50 seconds over ten contractions. Results showed that if the rest intervals were 50 seconds, the amplitude of the tenth contraction matched the amplitude of the first contraction. Thus, in order to achieve ten maximal EMS contractions, the 50-second rest interval was used.

If the rest intervals were 40 seconds, the last few contractions were of a lower amplitude than the first contraction. According to Kots, the attempt is being made to increase the CNS capacity by opening more pathways to the muscle by using EMS. The increase in pathways was found to be proportional to increasing the stimulation to optimum intensity. The major increase in the CNS is recruitment of nerve pathways in the peripheral system.

Kots found that gains in muscular strength were correlated to the number of treatments of the 10:50:10 routine. The author advocated daily treatments, five days each week, for a duration of seven weeks. A 15% to 20% increase in muscle strength was found after ten treatments, and increased to 30% to 40% after twenty treatments.

The results of EMS given on alternate days were similar to the results of EMS given daily, provided the same number of stimulations was given. The retention of muscle strength was maintained at approximately 90% of

the maximum for ten months after the stimulation sessions.

Kots noted an increase in the endurance capacity of the muscle after seven weeks of stimulations given daily, five days each week. Kots explained the result was due to an improved circulatory flow to the stimulated muscle.

The maximum increase in velocity of the stimulated muscle occurred after 10 to 15 stimulation sessions. Torque during a voluntary contraction was approximately 30% less than that of an electrically stimulated contraction. For a single muscle, the torque may be 10% to 15% less for a voluntary contraction than for the electrically induced contractions.

Summarizing the findings of Kots, the most viable routine is a 10-second contraction followed by a 50-second rest period, for ten consecutive contractions (10:50:10). Daily sessions five days each week yielded the best results. Maximal gains for velocity occurred after 10 to 15 treatment sessions. Maximal gains for strength occurred after 20 to 25 treatment sessions, and maximal gains in the endurance capacity of a muscle occurred after thirty-five treatment sessions.

Siemen's Electromedical Company (66) promoted monopolar and bipolar techniques. Monopolar stimulation was described as using two electrodes of different sizes, frequently a 2:1 ratio. The smaller active electrode should be placed over the motor point of the muscle or nerve, and the larger dispersive electrode should be applied some

distance from the stimulation site. The bipolar technique uses electrode plates of the same size applied directly over the muscle belly or functionally related muscle group. The muscle is permeated with current throughout the whole length. The cathode is the distally placed electrode. As a result of the lower current density under the equally sized electrode plates, the treatment caused minimal sensory and cutaneous discomfort. The current is able to be concentrated at the desired area of application. Daily treatment sessions were found to give the best results (66). Electrode plates should be placed on top of sponge pads soaked in tap water. Rubber straps are used to retain the electrode plates and sponge pads in place to ensure firm contact for current conduction.

Curwin et al. (9) used a medium frequency current which delivered pulses of 10 msec duration, every 20 msec, and at a frequency of 50 cps. The authors noted that bipolar stimulation of the quadriceps resulted in stimulation of the superficial muscles, whereas monopolar stimulation using the motor point of vastus medialis caused stimulation of the deeper quadriceps. The 10:50:10 routine given daily, five days per week for six weeks was followed for patients who had undergone anterior cruciate reconstruction. Muscle biopsies taken at regular intervals provided an analysis of enzyme activity. The medium frequency electrical stimulation caused a high degree of pain related to intensity of muscle contraction, and prevented

maximal output by the patient. Thus, the maximal contraction resulting from the stimulation was less than a maximal voluntary contraction, yet the results were still of importance. Complete details concerning the methodology were lacking.

Eriksson and Haggmark (12) in 1979 used one group which consisted of patients who had anterior cruciate ligament repair followed by the standard plaster cast and isometric exercise, and a second group which consisted of patients with similar pathology followed by the standard plaster cast, electrical muscle stimulation and isometric exercise. A cast window for electrical stimulation was cut over the distal aspect of the quadriceps muscle, and the anode was placed over the femoral nerve. Electrode plate size was not specified, nor was the type of current. The only detail given was that the frequency of current was 200 cps. Stimulation was of sufficient intensity to cause a tetanic quadriceps contraction. The EMS routine consisted of a 5 to 6 second contraction followed by a 5-second rest for a duration of one hour. Treatments were given daily, five days each week, for four weeks. Muscle biopsies were taken prior to and one week after surgery, and at the time of cast removal.

The technique used by Hartsell (21), involved the lower limb of one subject immobilized in a long cylinder cast. The lower limb was free of pathology. The cast window was cut over the motor point of vastus medialis for

the active electrode plate (6 cm x 8 cm). The dispersive electrode plate (6 cm x 8 cm) was placed over the femoral nerve in the femoral triangle. Sponge pads (7 cm x 9 cm) were soaked in ordinary tap water. The 10:50:10 routine was administered daily, five days each week for a duration of four weeks, twenty stimulation sessions in total. The Neuroton 627 was the machine used to deliver the square wave, 2.0 msec duration pulse, 65 cps and 60 mA. Measurements of muscle power, endurance, dynamic strength and isometric strength were recorded on the Cybex II isokinetic machine. Girth measurements were recorded over the belly of vastus medialis (located as 77.5% of the distance from anterior superior iliac spine to medial joint line), 10 cm proximal and 20 cm proximal to the belly of vastus medialis.

Currier et al. (8) studied healthy volunteers. The control group consisted of fourteen females, the isometric exercise only group consisted of seven females and four males, and the electrical stimulation group concurrent with isometric exercise consisted of ten females and two males. Training was completed daily, five days each week for two weeks, for a total of ten sessions. Isometric exercise consisted of a 6-second contraction followed by a 10-second rest period repeated six times. Electrical stimulation consisted of a rectangular pulse width, and intensity was maximally determined by each subject. The cathode (7.6 cm x 12.2 cm) was placed over the femoral nerve and the anode (7.6 cm x 12.2 cm) was placed distally

over the quadriceps femoris. The exercise technique for EMS duplicated that of the isometric exercise group. The authors' description of electrode placement contradicts the literature to date (9,21,23,63,66) as does the stimulation format (9,21,23,66) and may explain the lack of success by the authors. Both of Currier's treatment groups completed exercise on the Cybex II isokinetic machine with the lower limb at -60° knee extension. No rationale for the position of the lower limb was given. Pre and post-test measurements consisted of torque, and time-to-peak tension during one 6-second maximal isometric contraction. Of interest was the fact that five subjects developed either knee or back pain which was thought to have prevented maximal effort.

Godfrey et al. (15) assigned subjects with post-surgical or post-traumatic lower limb injuries to a group which consisted of isometric quadriceps exercise at 75% of the subject's maximal value, or to a group which received electro-stimulation. The isometric training group followed the 10:50:10 routine, in a seated position on a quadriceps table. The EMS group followed the 10:50:10 routine and was stimulated by fast repetitive tetanizing pulses at 60 cps. The active electrode was placed over the vastus medialis and the dispersive electrode was placed on the middle third of the anterior thigh. Treatment for all subjects was given daily. After three weeks, circumference measurements of the thigh taken 10 cm and 20 cm superior to

the adductor tubercle on a line with the anterior superior iliac spine, daily range of motion measurements, and maximum torque exerted by the quadriceps were recorded for pre and post-test measurements. Monopolar or bipolar technique was not specified, nor was electrode plate size.

Throughout the studies completed by Wise (63), a standard faradic unit delivering 50 cps and capable of producing a tetanic contraction was used. The Russian 10:50:10 routine was used and electrode placement was generally over the motor point of the muscle being stimulated and the appropriate nerve root. Current intensity bordered on intolerance to facilitate successful gains in muscle strength. Wise did not describe electrode plate size, position of the extremity during training, frequency of sessions, or the total duration of treatments prior to discharge or end of the training program. Wise inferred that a major factor influencing the results was that of using subjects considered to be above normal in muscle strength prior to the study (intervarsity wrestlers and basketball players).

Johnson et al. (23) in 1977 used the Neuroton 627 for faradic stimulation on patients with patello-femoral chondromalacia (P-FC). Fifty patients divided into severe and mild P-FC groups completed a 6-week program of the 10:50:10 routine given every second day. The machine delivered a pulse width of 0.1 to 2.0 msec, frequency of 65 cps and a square waveform. The active electrode (5 cm x 7.5 cm) was

placed distally over vastus medialis and the dispersive electrode (7.5 cm x 12.5 cm) was placed proximally over the femoral nerve. The knee was blocked in -5^{0} knee extension and a restraining strap was placed across the ankle. The subject was in a long-sitting position. Pre and post-test measurements consisted of thigh girth measured 7 cm and 15 cm above the patella, and isometric strength measurements at -90^{0} knee extension. No indication of a voluntary isometric quadriceps contraction concurrent with the EMS was given. Patients who had the shortest interval between treatments and the highest tolerated amperage demonstrated the best results. The greater the atrophy, the more effective the technique. Johnson et al. (23) suggested the result was a natural limit to the benefit capable of being derived from the technique.

Kots (25,26) in 1976, trained the biceps of one arm and the calf muscle groups of both legs of sumo-wrestlers. The "TU-1" unit, delivering right angle pulses at 50 cps and 1.0 msec duration was used. Square electrode plates (4 cm x 4 cm) were placed on both sides of the muscle belly being stimulated. Measurements of maximum arbitrary power, firmness of muscle contraction, and extremity circumference were taken. Subjects were treated daily for an average of fourteen treatment sessions. Current intensity was subjectively maximal. Results indicated that the right-angle impulses of 1.0 msec duration given at 50 cps developed the highest possible tetanic contraction of the

muscle fibres. Kots stated that stimulation of 100 seconds in total per treatment, given daily or every second day resulted in a significant increase in muscle power. Information regarding technique, frequency and actual routine for training was not available.

Williams and Street (61) used the old Smart-Bristow faradic coil to stimulate ten males and ten females who had undergone surgery for various knee pathologies. Subjects were placed in a long-sitting position with a block placed on the posterior thigh. Active electrodes were placed over the motor point of vastus medialis and two-thirds of the way down the anterior thigh. Two separate circuits were used. Daily treatments lasted twenty minutes and consisted of ten isometric quadriceps contractions with the EMS current followed by ten contractions induced only by the stimulation current. Definitive technique and descriptive methodology were lacking.

Hamilton (20) had all groups train three times per week for a duration of four weeks. The isometrically trained group performed three sets, maintaining six repetitions maximum (RM) for 15-second contractions. The isotonic group performed three sets at six RM. The electrodes for the EMS group were placed over the origin and belly of the biceps muscle. Current intensity bordered on intolerance, was administered with the arm in -90° elbow extension, and was given concurrent with an isometric muscle contraction. A 15-second work/rest interval was used for

ten repetitions.

Milner and Quanbury (41) in 1969 studied force, pain and electrode size in electrical stimulation of paralyzed lower limb muscles. Using cathode plates of 2.5, 5, 10 and 20 square cm applied over the motor point of the muscle, and a 30.5 cm square anode electrode placed proximally, stimulation was administered to eleven subjects. Results showed that electrode plate size was dependent on the area to be stimulated and the intensity of current density able to be tolerated by the subject.

Massey et al. (39), 1965, compared the effects of four methods of training on the muscle strength, girth, and grip strength of the upper limb. All groups trained three days per week, for a duration of nine weeks.

The EMS group received one 10-second maximal contraction (subjectively determined). The current was characterized by a frequency of 1000 cps, intermittent D.C. with a square wave and a rise time of 5 microseconds. The anode (23 cm x 23 cm) was placed on the trunk and the cathode (7.5 cm x 7.5 cm) was placed over selected muscle groups. The progressive weight-training group used dumbells of sufficient weight to allow them to perform two repetitions for each exercise, which increased to eight repetitions for the remaining four weeks. The static exercise group executed eight exercises whereby one 10-second maximal contraction was performed. The light recreational activity group participated in volleyball and swimming.

Strength measurements, grip strength, and girth measurements were taken prior to, after the fourth week, and at the conclusion of the study.

The technique used by Millard (40) was unsubstantiated. One group performed static non-weight bearing quadriceps exercises. A second group performed active flexion and extension exercises with partial weight bearing. A third group performed strenuous exercises. Subjects that received faradic stimulation had the knee flexed and blocked in -5° to -10° knee extension. Current intensity was sufficient to only raise the heel off the plinth. Current was a 1.0 msec pulse, square waveform, delivered at 50 cps at a rate of 30 times per minute. Electrode plates (7.5 cm x 7.5 cm) were placed at right-angles to the muscle fibres. Vastus lateralis, vastus medialis and rectus femoris were individually stimulated for ten minutes duration. The results were statistically non-significant and could be attributed to the treatment program used.

Studies and Uses of Electrical Muscle Stimulation

Kramer (34) in 1980 reviewed the Russian theories of muscle stimulation. Although muscle stimulation may be a valuable adjunct for rehabilitation, the general philosophy that voluntary exercise is of greater benefit for restoring muscle strength remains upheld. Previous Canadian studies that attempted to replicate Russian theories

and results failed to demonstrate significant increments with the use of electrical muscle stimulation as opposed to voluntary exercise for two reasons (9):

i) The stimulus must be of a sufficient intensity in order to produce a maximal or near maximal contraction of all the muscle fibres at a tetanus frequency.

ii) Pain must be minimal and since the low frequency faradic stimulation uses frequencies which are below those thought to maximally activate all motor units, especially the large motor units, increases in intensity to activate more fibres increase pain.

It was theorized that the Russians utilized a medium frequency current of sufficient intensity to activate all available motor units at a maximal tetanic frequency, but were able to minimize sensory discomfort at the same time.

The key factor claimed by Kots (27) was that the Russians were able to activate all available large and small motor units. Thus, it would be feasible to obtain electrical stimulation assisted contractions which produced 10% to 30% greater isometric tension than maximal voluntary contractions.

Kramer concluded that previous studies reported have involved the use of electrical muscle stimulation in the treatment of post-surgical knees, but that comparisons of studies were difficult as a consequence of different treatment techniques used, different current forms used, and different populations being treated with no controls.

Garrett et al. (13), 1980, attempted to determine if a specified type of EMS alone was capable of developing a

significant increase in strength of normal quadriceps muscle. After five weeks of training, significant differences ($p \leq .05$) were found between the control group (N=10), the isometric strength group (N=10), and the EMS group (N=10). A significant difference ($p \leq .005$) was found between the control and EMS groups. Also, a significant difference ($p \leq .0025$) was noted between the control and exercise groups. No difference was found to exist between the EMS and exercise groups. The authors concluded that the EMS did produce a strengthening of the quadriceps muscle. Thus, using EMS was better than not using anything, but had no greater effect than isometric exercise.

Godfrey et al. (15) in 1979, reported on the effectiveness of using fast repetitive tetanizing pulses to increase muscle strength. Utilizing post-surgical and post-traumatic patients (N=35), a comparison of the effects of isometric quadriceps exercise and electrostimulation on quadriceps strength was made. A significant improvement of both groups was observed, but a greater improvement in isokinetic quadriceps strength was noted in the group which received electrostimulation ($p \leq .05$). The authors concluded that although an increase in isokinetic muscle strength was found to occur with active isometric, isotonic, or isokinetic exercise, the use of tetanizing electrical stimulation (faradic current) was a more effective method of increasing or improving muscle strength.

The increased quadriceps strength with electro-

stimulation was not associated with the standard increase in bulk produced by other forms of exercise. Godfrey et al. (15) further stated that the implications for treatment with electrostimulation versus voluntary contraction were significant clinically, and the use of electrical stimulation could avoid a delay of patients who found it initially difficult in the rehabilitation to maintain a full voluntary contraction. The final and most relevant concluding statement was, "The next step would appear to be a study examining whether a combination of isometric exercises plus tetanizing stimulation would lead to greater strength increase in the quadriceps muscle following weakness caused by trauma or surgery" (15).

Currier et al. (8) compared programs of electrical muscle stimulation concurrent with a maximal isometric contraction and maximal isometric contractions alone. The authors' results showed a strength increase of 19% for the isometric exercise group (N=11), and an increase in strength of 21% for the electrical stimulation group (N=12). The results were statistically significant ($p \leq .05$). No significant change in the control group occurred. Currier et al. (8) concluded that electrical stimulation given concurrently with isometric exercise increased muscle strength over the control group but did not benefit the subjects nor provide greater enhancement of muscular strength more than conventional static exercise. The authors accounted for the results by stating that in

the past more beneficial results may have occurred using electrical stimulation with isometric exercise because earlier studies often utilized patients with lower limb pathology. Atrophic muscle is generally considered to be more responsible to this form or any form of rehabilitation than is normal healthy muscle. Currier et al. (8) also stated that the work intensity (6 seconds) followed by a short rest period (10 seconds) was a vigorous routine, but may have prevented maximal effort from some subjects as a result of pain, caused by muscular discomfort from contraction, skin sensory discomfort, or being unaccustomed to the activity.

Eriksson and Haggmark (12) studied quadriceps strength and enzyme levels following electrical stimulation given during a period of immobilization following surgery for anterior cruciate ligament reconstruction (N=8). Although the sample consisted of only eight subjects, results showed that subjects who received the standard plaster cast, isometric quadriceps exercises and electrical stimulation demonstrated less muscular atrophy and better muscle function than the subjects who performed conventional static quadriceps exercises in the standard plaster cast. A comparison of the succinate dehydrogenase (SDH) activity level calculated from muscle biopsies taken pre-operatively, one week after surgery, and five weeks after surgery when the cast was removed, revealed a statistically significant ($p \leq .05$) increase in the SDH

activity level for the electrical stimulation group as compared to the isometric group, when an analysis of the pre-operative and cast-removal data of SDH levels was made. The authors concluded that since SDH activity is well correlated with the ability of the muscle to perform daily work and engage in sports, electrical stimulation was more effective than conventional static exercise in the rehabilitation of the injured athlete. The athlete in the electrical muscle stimulation group demonstrated less muscular atrophy and better muscle function than the static exercise group.

Gosling (17) in 1979, concerned about the loss of quadriceps muscle integrity and patellar mobility as a consequence of immobilization and surgery, studied the effects of electromyographic (EMG) feedback of the quadriceps during immobilization of all patients. Observations suggested that upon cast removal after a program of in-cast stimulation, static quadriceps exercises and straight leg raises could be performed immediately. The technique resulted in an increased range of motion, decreased pain, and a reduction in the length of time necessary to regain normal function of the extremity. This method was used primarily as a means of feedback for muscle re-education or function and was only to the level of patient discomfort.

Curwin et al. (9) studied the clinical applications and biochemical effects of high frequency stimulation,

and the deterioration of muscle during immobilization which was shown to delay a return to activity. Subjects (N=unknown) having undergone anterior cruciate ligament repair, followed by standard immobilization, were placed in either the standard static isometric exercise group or the group which received electrical stimulation concurrent with standard static isometric quadriceps exercise. Analysis of muscle biopsies revealed no statistically significant differences in glycogen concentration between the two groups of subjects. However, the authors suggested that the result may have been due to other factors, such as diet, which may have affected glycogen concentrations, but were not controlled. Results showed that the adenosine triphosphate (ATPase) activity for subjects in the electrical stimulation group increased over time, but a decreased ATPase activity was observed for the control group. The authors concluded that use of the high frequency stimulator prevented some of the deteriorating biochemical changes which occur in immobilized muscle.

Hartsell (21) in 1979 studied the effects of electrical muscle stimulation on quadriceps muscle strength, applied during plaster immobilization of a normal healthy lower limb for four weeks. The lower limb was casted in -10° knee extension. Even though a single-subject case study, meaningful results were obtained as subject compliance with procedural format was controlled. Comparison of pre and post-cast girth measurements revealed no

atrophic changes in vastus medialis, the focal point of the EMS. Muscle function was good, and immediately post-cast there were no signs of reflex inhibition. A mild loss (-10°) of active range of motion was observed. Commonly, post-cast range of motion, in patients who did not receive in-cast muscle stimulation, was considerably less. The conclusion was drawn that with minimization of muscle atrophy and minimized loss of range of motion, oxygenation of the tissues and provision of nutrients were maintained, waste product removal and venous stasis were enhanced, and fibrous tissue build-up was prevented. Comparison of pre-cast and post-cast measurements on the Cybex Isokinetic unit demonstrated no change in muscular endurance which implied no impairment of waste product removal. Muscle power was minimally affected, and demonstrated a 30% loss from the pre-cast measurement. The least strength loss occurred at 30° of knee flexion. The loss was clinically significant since the last 30 degrees to full extension is the most difficult range to attain and maintain as a consequence of injury or immobilization, usually. Lieb and Perry (36,37) stated that the last 15 to 30 degrees to full extension requires quadriceps force to be 60% greater than for the previous range. As a consequence of no loss in muscle strength in the last 30 degrees to full extension no quadriceps lag resulted. Maximal strength loss occurred at 80° of knee flexion, and was one-third of the pre-cast value. The strength decrement represented a mean 1.0%

loss in strength per day at 80° knee flexion, a 0.8% loss in strength per day at 30° knee flexion. Various authors (32,43,56,59) have reported an average loss in strength of 1.3% to 5.0% per day. As a consequence, active progressive resistance exercises could be started earlier and at a more advanced level than cases where electrical stimulation was not given. Effectively, time required for rehabilitation was reduced. Full normal lower limb function was regained within twelve days post-cast. The author concluded that faradic muscle stimulation to the quadriceps concurrent with an isometric quadriceps contraction given during immobilization was a valuable mode of treatment to maintain muscle bulk or prevent muscle atrophy, negate the undesired effects of immobilization and permit rehabilitation to commence at a more advanced level, thereby reducing overall rehabilitation time.

The effects of faradic muscle stimulation on skeletal muscle fibre area were studied by Taylor et al. (57) in 1978. Results of the 11-subject heterogenous group, based on pre and post-training muscle biopsies of vastus lateralis demonstrated that faradic muscle stimulation did not affect the fibre area or distribution of fibres, but that slight improvements in muscle strength were noted.

Wise (63) investigated the therapeutic uses of 10:50:10 faradic stimulation for muscle strength gains, and the strengthening benefits of 10-second tetanic muscle stimulation. Wise initially attempted to duplicate the

results from Russian studies which reported that EMS generated greater increases in strength than did voluntary isometric training. With no explanation, Wise stated that results from the application of EMS to the lower limb of male intervarsity basketball players (N=12) showed no statistically significant differences among the groups, with reference to vertical jump measurements. The same technique applied one year later to the upper arms of intervarsity wrestlers (N=unknown) yielded significant increases in muscle strength for subjects in the EMS group. Wise performed a third study using EMS with isometric exercise to the elbow flexors, and noted significant improvements in elbow flexor strength. The same author began an EMS protocol for P-FC, post-surgical patients, and fracture patients (N=unknown). Wise noted increases in isometric muscle strength after twenty stimulation sessions, and implicated uses of EMS to be beneficial in late stages of immobilization following surgery, and for uncomplicated fractures. In-plaster muscle stimulation was associated with less atrophy than expected after immobilization and less joint stiffness. Wise found that post-operative, electrical stimulation reduced the incidence of P-FC or patellar tendonitis, and promoted earlier strength gains of vastus medialis. The author concluded that the 10:50:10 faradic stimulation regime produced significant strength increases if the muscles were stimulated repeatedly to limits of maximal tolerance. However, these studies are unpublished

and used small groups of subjects.

Johnson et al. (23) in 1977 studied the effects of the Russian faradism technique of 10:50:10, on the symptomatic treatment of fifty cases of P-FC. The triangular waveform utilized in the initiation period progressed to the rectangular waveform. A comparison of isometric, isotonic, and isokinetic exercise for the strength restoration of the vastus medialis muscle was made. The results showed a 25.3% increase in quadriceps strength for patients with mild P-FC and an increase in quadriceps strength of 200% for severe P-FC patients. An increase of 4.3% and 6.8% in thigh girth was noted for mild and severe P-FC patients respectively. The authors concluded that faradic stimulation was a useful mode of treatment for P-FC and that the greatest benefit of faradism was that of combating the lost voluntary control of the quadriceps. The concept being utilized is one of muscle re-education rather than strength improvement of available voluntary motor units. Furthermore, no comparative groups were utilized and the 200% strength gain for the severe group may be related more to their initial low level of strength than to the form of treatment.

In 1977, Kots (27) presented a symposia at Concordia University concerning the Russian technique of faradic muscle stimulation. Kots claimed that his Stimula I delivered a current similar in effect to the Canadian faradic muscle stimulators, but did not have the same painful

skin sensory discomfort. Deviating slightly from his regular 10:50:10 routine, Kots demonstrated reduced back pain, increased flexion and improved muscle tonus, after seven days of treatment on a chronic low back problem. Kots and his associates managed to eliminate or minimize the pain factor permitting heavier current intensities and inducing stronger muscle contractions. Details pertaining to the Stimula I circuitry are unavailable.

One year earlier, in 1976, Kots (25) is reported to have claimed to be able to increase the strength of a muscle by 40% after only twenty EMS treatments. Kots did not specify the voltage but it was stated (9,22) that the frequency used by Kots was 2500 cps. Utilizing his 10:50:10 routine, Kots stated that the voluntary exercise induced by the treatment routine recruited 100% of the muscle fibres, and consequently increased the strength and the density of the muscle without increasing the diameter of the muscle, nor inducing fatigue. Kots stated that an individual could voluntarily only call 80% to 90% of the muscle fibres into action. In addition to demonstrating strength increments in electrically stimulated muscle, an increase in the velocity of a muscle contraction was also demonstrated.

Realizing that failure of the proper function of the vastus medialis seriously impairs the whole of the extensor mechanism of the knee and that after knee joint trauma quadriceps muscle strength is difficult to attain,

Williams and Street (61) investigated the use of sequential faradism towards alleviation of the negative effects of injury to the knee joint. Patients who had undergone surgery for various knee pathologies were treated with EMS concurrent with standard isometric quadriceps exercises to the vastus medialis. After fourteen daily stimulation sessions, the authors concluded that sequential faradic stimulation of the vastus medialis, and quadriceps muscle group in general, was a useful addition to the conventional techniques of knee joint rehabilitation.

In an unpublished article, Kots (25,26) reported on the training of muscular power by electrical stimulation, and attempted to establish an electrostimulation routine. Stimulation of the biceps of one arm and calf muscle group of both legs of sumo-wrestlers, produced results which indicated that 1.0 msec square wave impulses at 50 cps developed the highest possible tetanic contraction in the stimulated muscle. An investigation of the duration of irritation showed that the training effect of the electrical stimulation was related to the contraction of the muscle, induced by EMS. This result lead to the formation of an EMS routine whereby the quality of the tension of the muscle was to be unchallenged during the action of the electrical current. The average occurred within 12.5 seconds after the beginning of the electrical stimulation. Results of EMS training on the sumo-wrestlers showed an average increase in arbitrary muscle power of 38.4% and

50% for the biceps and calf muscles respectively, after nineteen sessions of EMS. Kots concluded that total stimulation of 100 seconds per treatment given daily or every second day using the 10:50:10 routine, resulted in a considerable increase in muscle power, and was due to a working hypertrophy of the muscle fibres being trained.

Eriksson (11) studied the effects of electrical muscle stimulation on cases of fifty casted post-operative knees. Eriksson stated that it was of importance to return an athlete to their sport as soon as possible. To prevent quadriceps atrophy during immobilization, he advocated the use of a cast brace. Through muscle biopsy he found the slow-twitch or oxidative fibres atrophied the most in the injured athletes. Also noted with muscle atrophy was a drop in the level of SDH, but not in the level of phosphofructokinase, which implied a decrement in the oxidative potential of the quadriceps.

When Eriksson compared the physiological effects of an injured athlete wearing a standard cast and performing voluntary isometric exercises to an injured athlete wearing a standard cast and receiving transcutaneous nerve stimulation of the quadriceps, a noted drop in the level of SDH was prevented with the stimulation. Eriksson concluded that the best treatment of choice would be electrical stimulation with cast-bracing.

Hamilton (20) in 1975 compared the effects of isometric, isotonic and EMS training programs on upper limb

muscle strength and muscle hypertrophy using one RM cable tensiometer tests, and fat-corrected arm girth measurements. Pre and post-test measurements of both arms of male volunteers randomly assigned to the training groups showed significant differences for measures of one RM and non-dominant cable tensiometer and fat-corrected arm girth for the isometric group. The EMS group showed significant increments for fat-corrected arm girth, one RM test, and cable tensiometer tests. The isotonic exercise group showed no significant change. A comparison between results of the EMS group and the isometric exercise group revealed no significant difference for one RM and non-dominant cable tensiometer measures. Hamilton concluded that EMS produced significantly greater increases in isometric strength, isotonic strength and muscle hypertrophy than either the isometric or isotonic training programs. However, the data remains unpublished.

Massey et al. (39), 1965, investigated the benefits of high frequency EMS for improving muscular efficiency. Nine weeks of training forty-seven normal healthy marines divided into four groups occurred. Group A trained with EMS; group B trained using progressive weight-training; group C trained using isometric exercises; and group D was involved in light recreational activity. Results indicated that the group training with progressive weight-training showed the greatest increases in mean developmental strength. The static exercise group, the EMS

group, and recreational activity followed respectively. The order also proved to be the same for the amount of time spent on training for each group. Even so, the authors concluded that using EMS to strengthen muscle was more effective than light recreational activity, but was no more effective, if as effective, as progressive weight-training or static exercises.

Millard (40) in 1952 studied the effects of faradic muscle stimulation on facilitation of the disappearance of a post-traumatic knee effusion (N=171). He compared patients receiving voluntary exercise and EMS during rehabilitation. Intensity of the faradic stimulation was only strong enough to minimally raise the patient's heel off of the plinth. Results showed no significant difference in increments of muscle power between the groups. Less atrophy was noted with the EMS group. No difference in average treatment time to discharge between groups was noted, nor did the time necessary for a knee effusion to disappear alter between the groups. Millard concluded that faradic stimulation of the quadriceps was of no real value in aiding the recovery of either muscle power or bulk, and that faradic stimulation did not accelerate the disappearance of a knee effusion.

<u>Isometric and Isokinetic Exercise</u>

Rozier et al. (52) studied the effects of daily isometric exercise in the prevention of strength loss of the

quadriceps during long-cylinder immobilization, for nine days. Measurements taken before and after immobilization included girth measurements and isometric strength at 90° knee flexion. The test group performed daily isometric quadriceps exercise of five repetitions, and 6-second isometric contraction followed by a 6-second rest. Their results and conclusion stated were that isometric quadriceps exercises performed while the limb was casted did prevent significant strength loss.

Komi et al. (30) in 1978 reported that after 12 weeks of maximal isometric knee extension exercises, performed at 50° knee flexion, given four times each week, a significant increase in muscle strength (20%) occurred in the trained leg and an 11% increment occurred in the untrained leg. An increase in enzyme levels of malic dehydrogenase, SDH and hexokinase as calculated from post-test muscle biopsies occurred, but lower levels of lactate dehydrogenase and creatine kinase were noted. In addition to increments of levels of malic dehydrogenase and SDH, the enhancement of aerobic metabolism in the exercise leg was substantiated by a 29% increase in endurance time when measured at 60% of the pre-training maximal force.

Murray et al. (46) in 1977 documented ranges of normal variability in torque of the knee flexor and extensor muscles during maximum isometric contractions at joint angles of -30°, -45°, and -60° knee extension. Results showed that mean extensor muscle torque was higher than

mean flexor muscle torque at all angles. The highest mean torque for the quadriceps occurred at -60° knee extension, and was 45° knee flexion for the hamstring muscles. Test and re-test were completed one week apart. Mean torque values were higher on the re-test for both muscle groups, but were only statistically significant for the quadriceps at -60° knee extension. The authors stated that two trials were necessary in determination of maximal strength due to discrepancies in successive attempts which should allow a 90-second rest interval between contractions. The concept of the subjects learning to perform the test manoever was not cited as a possible reason for the results.

Schenck and Forward (53) investigated the possibility of maximal isometric contractions remaining the same over repeated trials or whether a meaningful change was noted. Subjects were tested at -60° knee extension on a weekly basis for a duration of six weeks. Results indicated a significant increase in scores up to the third test, after which a levelling off to non-significant differences occurred. The authors concluded that the subject should be familiar with the testing procedure so that a quantitative levelling of the behavior tested would be reached before the experiment had begun, or to institute a control group. The strongest correlation existed when the testing procedure duplicated the training procedure.

Zohn et al. (64) studied the rapidity of recovery from knee injuries by a comparison of isotonic and

isometric exercise. The treatment duration, muscular strength increments, cross-education and muscle hypertrophy were noted. The subjects trained daily, five days each week. Subjects performing isotonic exercise required 25% more treatments than subjects who performed isometric exercise ($p \leq .05$). The authors concluded that an isometric routine permitted more rapid rehabilitation than the isotonic routine.

Johnson and Siegel (24) investigated the reliabilities that might be expected over a number of trials and days for isokinetic movement of the knee extensors. Subjects exerted a maximal force from -90° to 0° knee extension. Six trials with a 20-second rest interval between trials, were completed daily for three consecutive days. From an analysis of the results, the authors concluded that a protocol which provided for three submaximal trials followed by three maximal warm-up efforts was essential before stable measures were manifested in measurement of isokinetic force of the knee extensors.

Osternig et al. (47) in 1977 examined the relationship between maximal isometric forces generated at specified angles and isokinetic torque forces. Results indicated slight tendencies for the significant correlations to cluster around the slower speeds and towards the greater angles of elbow flexion. The authors concluded that measures of maximal isokinetic strength cannot be used to predict the isometric strength capabilities even at the

same angle within the range of joint movement.

Thorstensson et al. (58) designed a study to characterize isokinetic contractions and examine force-velocity relations in the knee extensors of humans, and also to determine the correlation of fibre composition of the contracting muscle with the dynamic muscle force at different shortening velocities. Results showed that at any given knee angle torque produced was higher for isometric than for dynamic contractions and with increases in angular velocities the torque produced decreased. The decrease in torque was less marked at the small angles. The study showed that true isokinetic contractions and torque registered a high reliability when using the Cybex II. Correlations were produced between the peak torque produced at the highest speed of muscle shortening, and the relative area of fast twitch fibres in the contracting muscle. Muscles with a high percentage of fast twitch fibres had the highest maximal contraction speeds. Dynamic torque decreased gradually with an increased speed of shortening.

Tipton et al. (59) studied the effects on non-trained rats of thirty minutes of running on the junction strength and weight of the medial collateral ligament. Finding no difference they immobilized one hind leg in plaster for six weeks. Results indicated that the junction strength of the medial collateral ligament of the casted leg was lower than that of the uncasted leg. They concluded that during immobilization, junction strength of the medial collateral

ligament decreased.

Rosentswieg and Hinson (51) in 1972 examined differences among isokinetic, isotonic and isometric contractions in terms of electrical activity elicited by each type of exercise. Results showed that isokinetic contractions elicited significantly greater electrical activity than either isotonic or isometric contractions. No significant differences were found among the muscle action potential at various angles of elbow flexion during the isometric or isokinetic contractions.

Through an investigation of previous studies, Muller (43) stated that the rate of strength increments with maximal exercise is approximately 12% per day, but that in the absence of any muscle contraction, a loss of strength occurred at 5% per day. One muscle contraction daily at 50% of maximum was enough to prevent a decrement. The functional capacity of a muscle increases with use and decreases with lack of use. Muscular atrophy was reported to begin within several days of muscle inactivity.

Muller concluded from studies involving isometric training that the rate of strength increments was accelerated by a longer duration of contraction time and that daily maximal contractions maintained a prolonged stimulus near maximal levels. Thus the most rapid increases in muscular strength would be guaranteed. During immobilization muscle loses strength at the rate of 1.3% to 3.0% per day, but if the immobilized muscle performs daily isometric

contractions, then the rate of atrophy is reduced. One contraction per day at 10% to 20% of the maximal strength prevented atrophy. Muller stated that maximal strength was regulated by the intensity of frequent muscle contractions, that stronger contractions act as a stimulus to increase strength, and that reduced effort lowers the stimulus to maintain strength.

Kottke (32) discussed the effects of limiting physical activity on muscles. Muscle strength was maintained by frequent contractions which produce tension. The stimulus to increase muscular strength was the maximal tension or maximal rate of metabolic activity produced during a muscle contraction. A muscle contraction which produced maximal tension was more effective to increase strength than many contractions at a lesser tension. Isometric contractions of 6 to 10 seconds duration at maximal tension, exerted several times daily, produced a strength increment of 10% per week. As tension during each contraction fell from 100% to 30% of maximum, the stimulus to increase strength progressively decreased. A daily isometric contraction at a tension of 20% to 30% of maximum was enough to maintain strength. If no muscle tension was exerted daily, strength was lost at a rate of 3% per day.

Reduced endurance time, increased adhesion formation, and reduced neuromuscular activity were all related to the level of muscular activity and strength development.

In 1947, Smart (56) made the conclusive remark,

> "... in our effort to aid Nature to accomplish repair during and after inflammation of joint structures this important feature has not received the general attention it deserves, ... I do not deny that the importance of the restoration of muscle function after muscle injury is now much more fully realized than it was formerly."

Through disuse muscle atonicity and atrophy occur. If muscle tone is first restored by electrical stimulation, then growth of muscle fibres at a greater rate and efficiency occurs than with exercises alone.

During the early stage of rehabilitation, electrical muscle stimulation was a good aid to natural repair of muscle tonus and strength. Healthy muscle was capable of protecting a joint, but atonic muscle was incapable of full and rapid contraction, and thus a joint would be limited in action, and nutrition of other structures interfered with due to a decrease in circulation resulting from the loss of the muscle pumping action.

Muscle action aids circulation, local and general metabolism, and clearance of waste products. Blood supply to a muscle in action is eight times greater than that of a muscle at rest (56). Muscle action reduces pain by preventing harmful effects of prolonged interference with circulation. Pressure effects cause excessive intercellular tension, slowing of intracellular movements, pressure on and stretching of tissues, and pressure on nerve endings which further slows local circulation and increases pain.

Repair of damaged tissues, prevention of blood and lymph stagnation may be achieved by treatment designed to produce muscular contractions and relaxations. Smart (56) stated that muscle function whether naturally or electrically produced acts as a powerful stimulus in preventing stagnation of fluids. Lack of physical muscle movement:

a) causes loss of function, contractures in muscle, adhesions in joint capsule and ligaments, a decreased range of motion due to coagulation of exudate, and increased pain.

b) affects the stretch reflex in atrophic muscle, causes a reflex inhibition, and reduces protection of joint structures.

c) upsets synergistic movement and influences the balance of precision movements of wasted muscles attempting to work.

d) upsets the balance of muscle contraction and relaxation which facilitates reciprocal inhibition.

Smart further stated that stimulative muscle action is the greatest aid to the natural repair of joint tissues via voluntarily produced muscle action, and the correct application of the proper type of electrical current.

In the past, EMS research has involved combinations of healthy, injured, or traumatized muscle, casted or uncasted limbs, low, medium or high frequency stimulators, different electrode plate placements, and varying current waveforms. Lack of detailed information concerning the procedure of some studies exists. Consequently, comparisons between previous studies and definitive conclusions

pertaining to the use of EMS to increase muscular strength remain unknown.

The need to investigate and establish EMS techniques and procedures is imperative if optimal benefits from the use of EMS during rehabilitation are to be realized.

CHAPTER III

METHODOLOGY AND PROCEDURE

Methodology

Twenty-one male student volunteers ranging in age from 18 to 35 years participated in the study. All volunteers were informed as to the format, training programs, safety, and duration of the study. None of the subjects had a recent history of significant lower limb pathology.

The Cybex II Isokinetic Exercise Unit was utilized to record the isometric strength of the right quadriceps at 60° of knee flexion. The scores were ranked highest to lowest. A stratified random design was used to place the subjects in groups. From the top four scores, a subject was randomly placed into one of the four groups. The procedure was repeated until all subjects were placed in a group.

All subjects were required to sign the informed consent form (Appendix A) prior to the start of the study.

The total treatment routine for each group required a period of six weeks, exclusive of the pre-treatment and post-treatment measurements. During the six-week training period, subjects were requested to limit participation in physical activity which deviated from their stated norm. Weekly, each subject was requested to complete an activity record sheet (Appendix B).

For all groups, the right quadriceps was tested and

treated. Group I, the control group, participated only in the pre-treatment and post-treatment measurement sessions. Group II completed an isometric exercise routine. Group III completed a routine of monopolar electrical muscle stimulation to the vastus medialis muscle, concurrent with a maximal isometric quadriceps contraction. Group IV completed a routine of bipolar electrical muscle stimulation to the vastus medialis muscle, concurrent with a maximal isometric quadriceps contraction.

Electrical muscle stimulation was administered using the Seimens Neuroton 627 (Figure 1). This unit was selected because it is capable of producing the high intensity, prolonged tetanic contractions necessary for the electrical muscle stimulation techniques investigated. Individual pulse time may be manually selected up to a maximum of 2.0 msec.

Pulse forms for the faradic current may be square or triangular. The square waveform was selected to prevent accommodation, and to provide a fast rise-time output. The pulse frequency was 65 cps and the maximum current output was 60 milliamperes (mA). Maximum voltage was 110 volts (V).

The post-treatment measurement technique duplicated the pre-treatment measurement technique. Testing utilized the Cybex II Isokinetic Exercise Unit and Dual Channel System (Lumex Incorporated, New York) (Figure 2). The machine was calibrated prior to each testing session. The

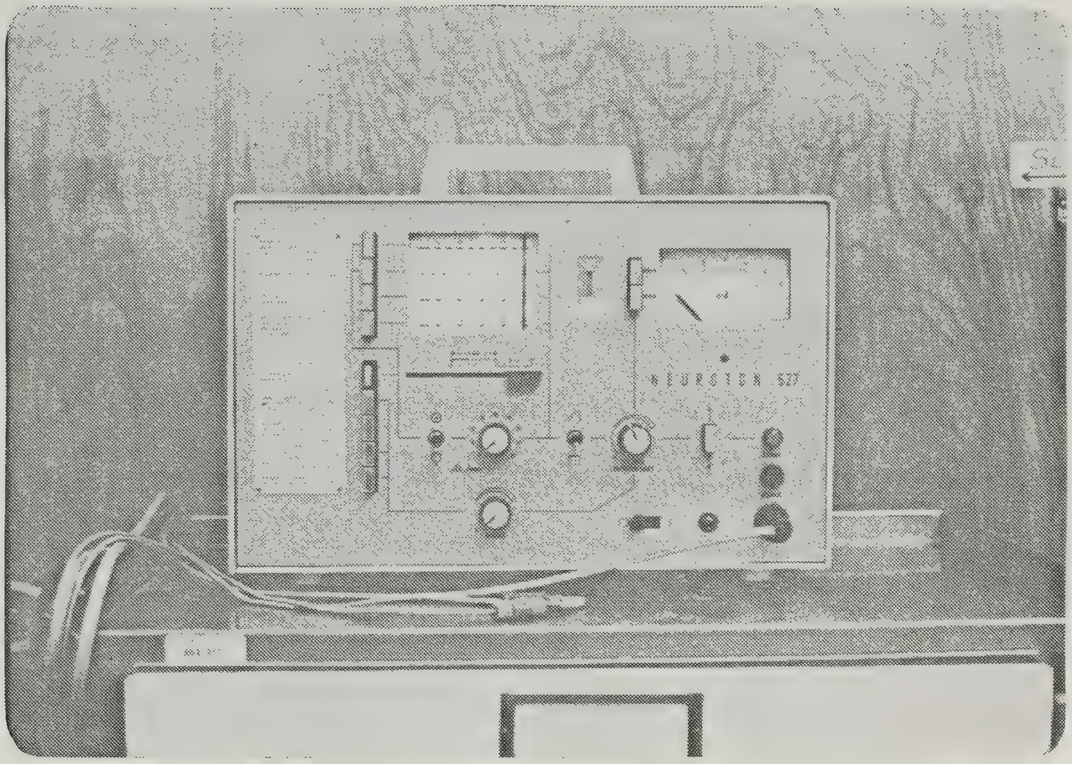

Figure 1

Neuroton 627

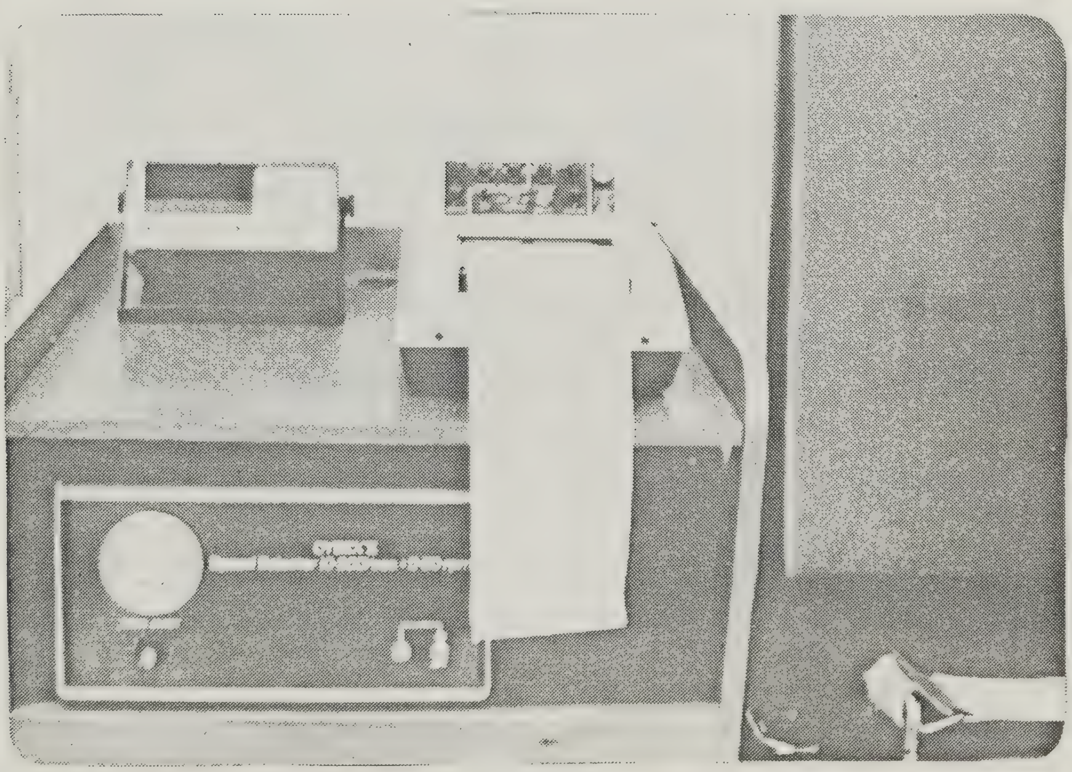

Figure 2

Cybex II Recorder

Cybex II has a built-in electrogoniometer, a Digital Work Integrator, and a dual-channel instrumentation system designed to measure and record dynamic strength, power and endurance, simultaneously with range of motion. The advanced Dual-Channel Recorder precisely displays specific torque development parallel to joint angle.

The pre-treatment and post-treatment measurements (Appendix C), on the right lower extremity for the subjects in all groups consisted of the following:

a) Girth Measurements

With the leg relaxed, in extension, and the heel resting on towels to clear the thigh from the table, the following girth measurements were taken (Figure 3):

1. A circumferential girth measurement in centimetres (cm) was taken at the mid-belly of vastus medialis, located as 77.5% of the distance from the anterior superior iliac spine to the medial joint line of the right lower extremity (21) (Figure 4).

2. A circumferential girth measurement (cm) was taken at mid-quadriceps, located as 50% of the distance from the anterior superior iliac spine to the medial joint line of the right lower extremity (21).

The two girth measurements at different locations on the thigh were recorded in an attempt to identify where specific changes due to various methods of training occurred. At 77.5% of the distance from the anterior superior iliac spine to the medial joint line, the vastus medialis muscle was measured in "isolation", since the remaining quadriceps and hamstring muscles are predominantly tendinous at

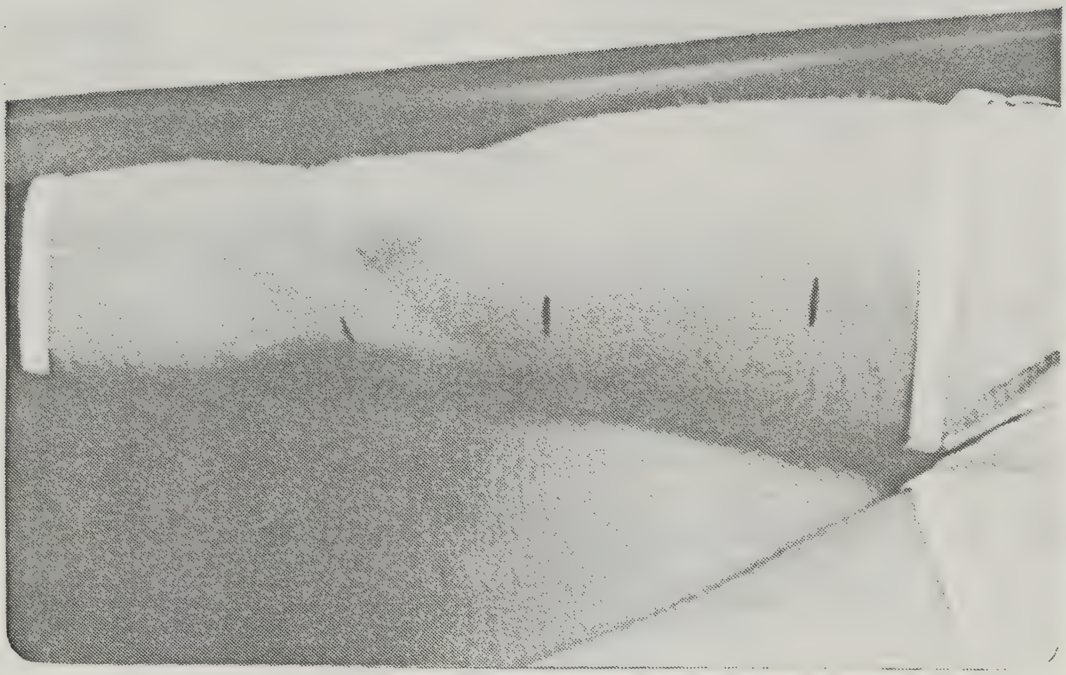

Figure 3
Medial Joint Line and Girth Measurement Locations

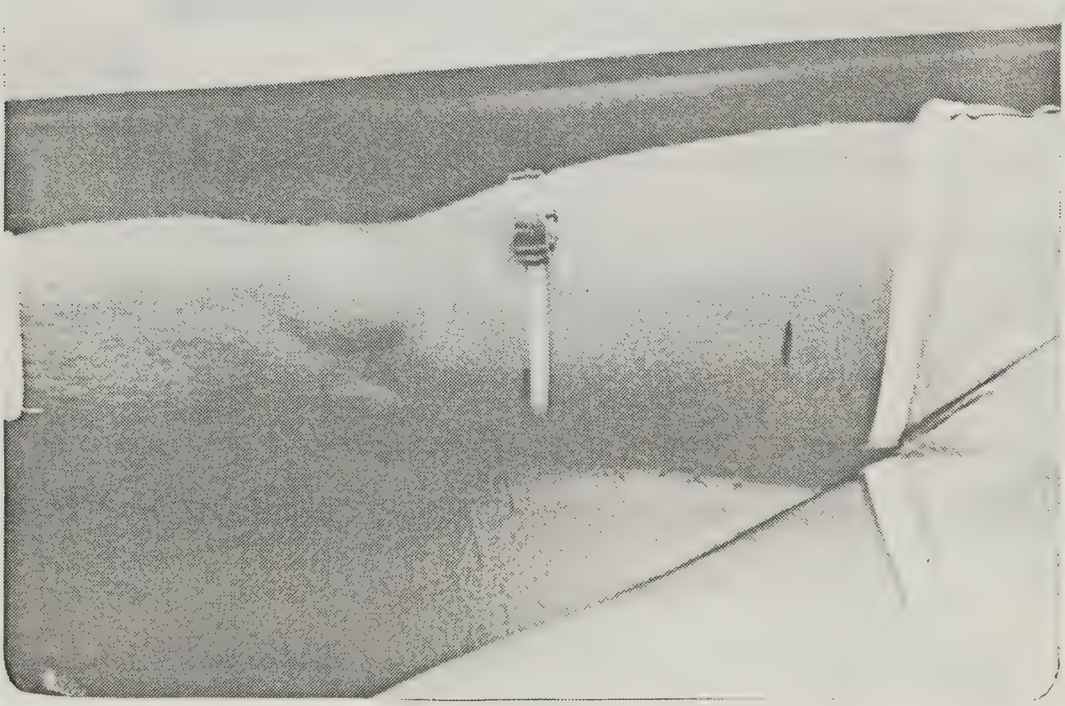

Figure 4
Girth Measurement at 77.5%

the 77.5% level. At 50.0% of the distance from the anterior superior iliac spine to the medial joint line, a general measurement of the quadriceps muscles was recorded.

b) Isokinetic Measurements

Subjects were seated on the padded testing table with the knee joint centre of the right lower extremity aligned with the rotational axis of the Cybex II input shaft. The hip was positioned in neutral abduction/adduction. Attached to the radial arm of the Cybex II was a leg pad, which was comfortably strapped proximal to the ankle on the anterior aspect of the lower leg, and permitted normal dorsiflexion at the ankle joint. Stabilization to prevent hip and trunk motion was achieved by means of the use of a backrest (75^{o} hip flexion) and a shoulder harness which was securely fastened to the testing table. A padded strap attached securely to the testing table was placed across the distal one-third of the right anterior thigh, which ensured stabilization (Figure 5). Verbal instructions included commands to begin and to terminate the contraction, as well as commands of encouragement during the effort. The subject continued to perform a maximal voluntary contraction until instructed to stop. A maximum of three practice trials was permitted prior to each test.

1. Dynamic strength was measured by having the subject contract throughout an active range of motion from -90^{o} to 0^{o} knee extension. A maximum

Figure 5

Subject tested on Cybex II Isokinetic Exercise Unit

rotational test velocity of 30^{o}/second (^{o}/sec) and a chart paper speed of 5 millimetres/second (mm/sec) were used. The subjects performed three consecutive maximal effort contractions in both directions of extension and flexion.

2. Instantaneous power was measured by having the subject contract throughout an active range of motion from -90^{o} to 0^{o} knee extension. A fast maximal rotational test velocity of 180^{o}/sec and a chart paper speed of 5 mm/sec was used, as reported by Lumex Incorporated. A verbal explanation that this test differed from the dynamic strength test was given. The explanation clarified that the subject was to perform "explosive", powerful reciprocal contractions and that he would feel less resistive loading than during the dynamic strength test since the musculature was developing less force output at this faster contractile velocity. The subject performed three consecutive maximal effort contractions in both directions of extension and flexion.

3. Endurance was measured by having the subject contract throughout an active range of motion from -90^{o} to 0^{o} knee extension and continued repetitions until peak torque reached 50% of the initial maximal value for the quadriceps. A fast maximal rotational test velocity of 180^{o}/sec and a chart paper speed of 5mm/sec were used. The subject was asked to concentrate on performing "explosive", powerful reciprocal contractions, and informed that he would feel less resistive loading than the dynamic strength test because the musculature was developing less force output at this faster contractile velocity.

4. Isometric strength was measured at -15^{o}, -30^{o}, -45^{o} and -60^{o} knee extension. Zero rotational test velocity, and a chart paper speed of 5mm/sec were used. The subject was required to exert maximum effort until a consistent peak on the graph was attained. Two isometric contractions at each joint angle tested were given. A 90-second rest interval between contractions was permitted.

Procedure

Treatment sessions were conducted by the investigator, and all verbal commands during the treatment sessions were consistent from subject to subject. Treatment sessions for each subject in groups II, III and IV were conducted daily, five days each week, for a duration of six weeks.

Treatment Position for Groups II, III and IV

The position of the subject receiving treatment was standard for groups II, III and IV.

1. The subject lay supine on a plinth, and was permitted to grasp the sides of the plinth. A restraining strap was placed across the pelvis at the level of the anterior superior iliac spines (Figure 6).

2. The right knee was flexed over a standard knee board, and maintained at 20° to 30° of knee flexion (Figure 7).

3. Extension of the right knee was isometrically restrained by a canvas strap placed across a pad, proximal to the ankle joint, and full dorsiflexion at the ankle was allowed (Figure 8).

Treatment Routine for Electrical Muscle Stimulation Concurrent with Isometric Quadriceps Exercise

The square waveform for the electrical muscle stimulation current was selected. Maximal current intensity was 60 mA, and the duration of the pulse was 2.0 msec.

1. The subject assumed the treatment position.

2. The active electrode plate and sponge pad moistened in tap water, were positioned as described. The electrode plate and sponge pad were securely fastened in place with an elastic wrap which ensured total electrode surface area contact.

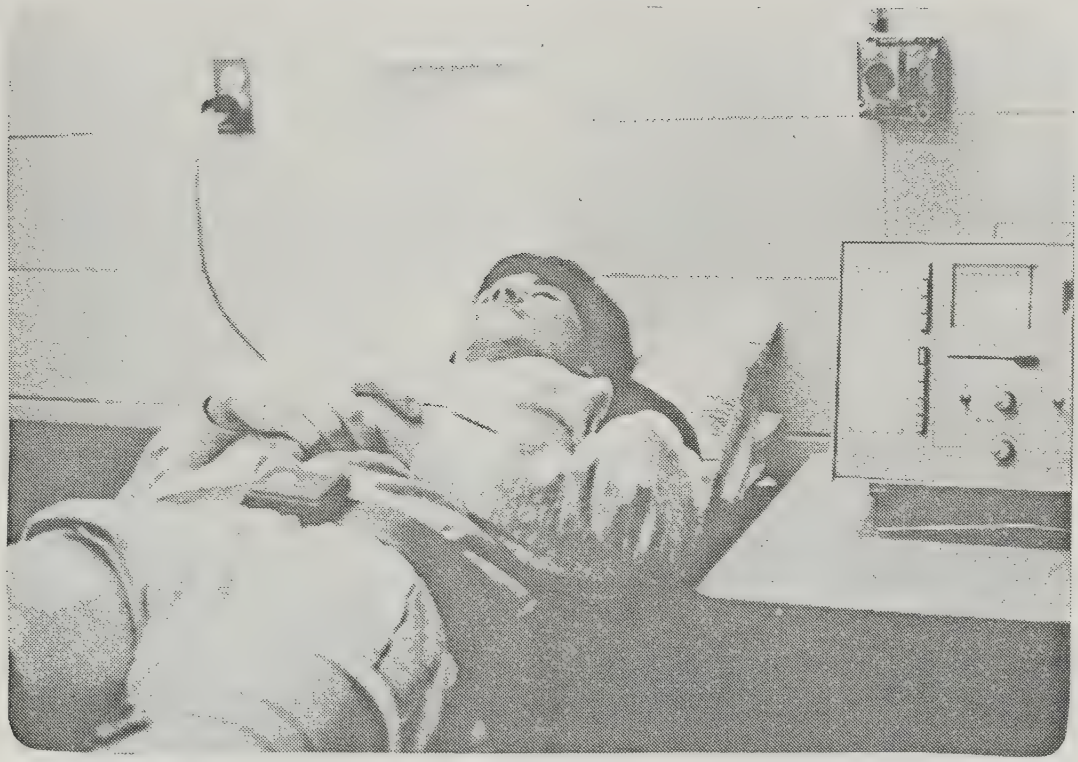

Figure 6

Treatment Position for Experimental Groups

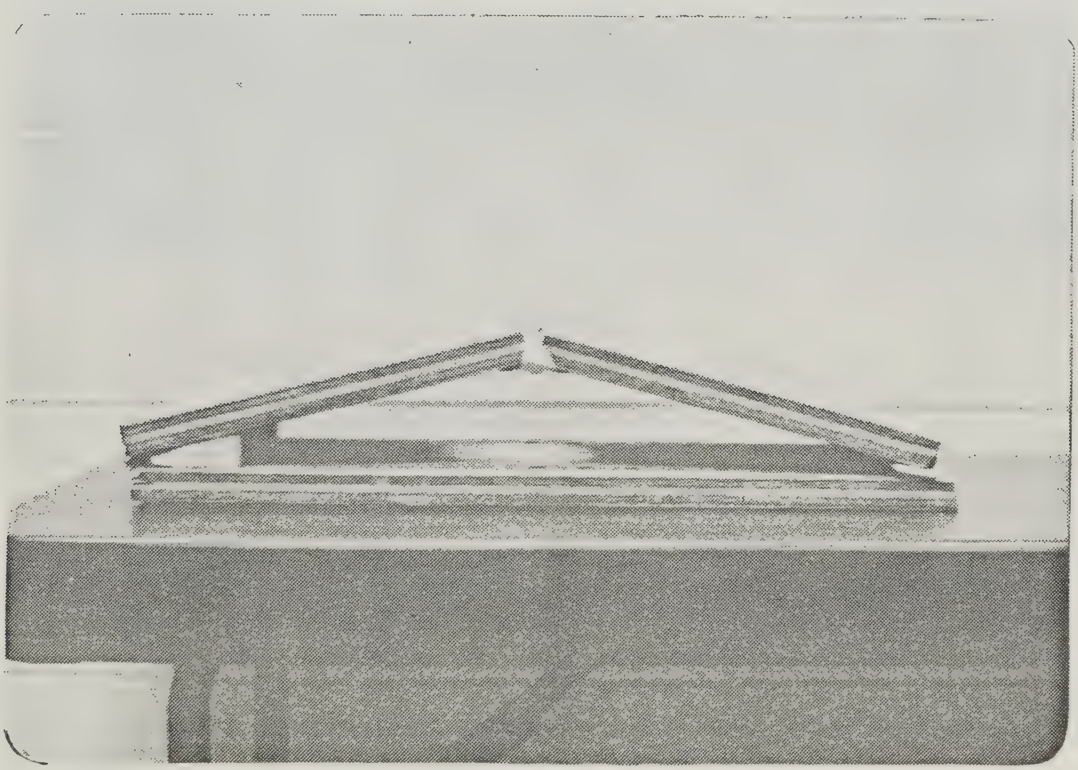

Figure 7

Standard Knee Board

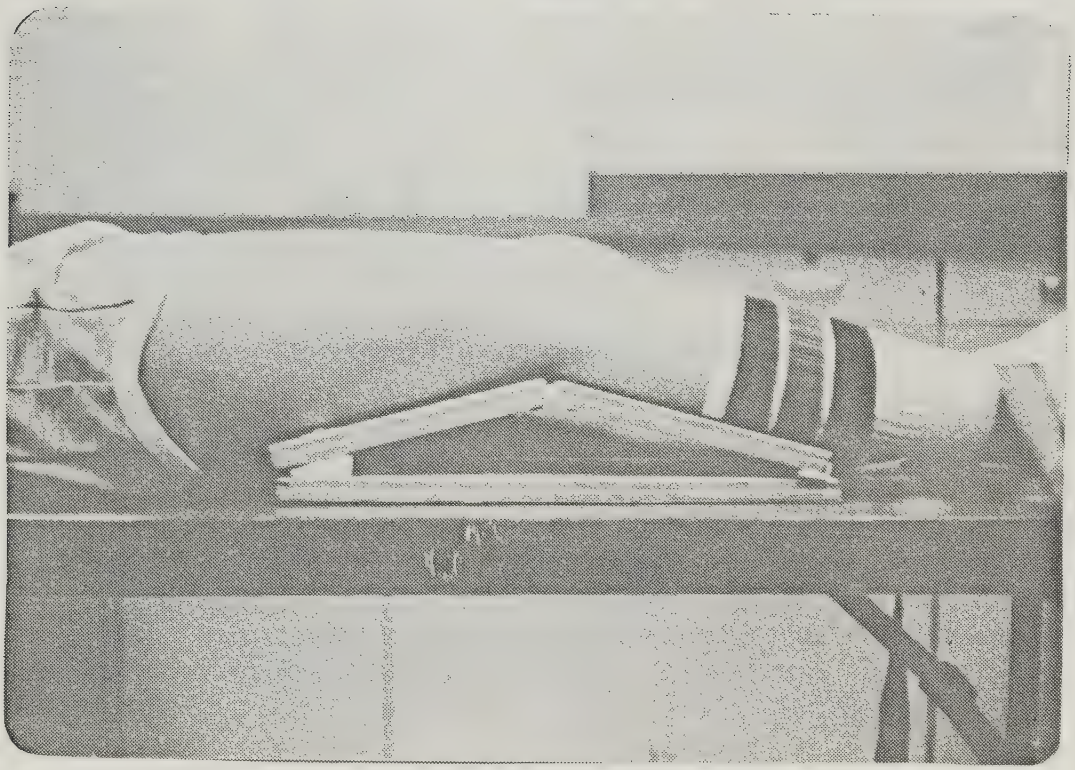

Figure 8
Leg Position over Standard Knee
Board for Experimental Groups

3. The dispersive electrode plate and the sponge pad prepared as described in 2, were placed in position.

4. The maximum current intensity, concurrent with a maximal isometric quadriceps contraction, able to be tolerated by the subject was determined.

5. Concurrent with the current being switched on, the subject was instructed to maximally contract the quadriceps isometrically, full dorsiflexion at the ankle joint. The combination of electrical stimulation and maximal isometric quadriceps contraction was maintained for a duration of 10 seconds. The subject was permitted to hold his breath, or to breathe normally, as determined by personal preference.

6. With a goniometer appropriately positioned on the right lower extremity, the knee angle was measured prior to the completion of the first effort.

7. A 50-second rest period followed.

8. The procedure was repeated until ten contractions had been performed.

9. The mA intensity was recorded for the first and tenth contractions, for each training session (Appendix D). The intensity was adjusted during each treatment according to personal tolerance as indicated by the subject.

Group II - Isometric Quadriceps Exercise

1. The subject assumed the treatment position.

2. The subject was instructed to extend the lower limb with maximum effort and to maintain the intensity of effort for a duration of 10 seconds. The ankle was fully dorsiflexed. The subject was permitted to hold his breath or to breathe normally, determined by personal preference.

3. With a goniometer appropriately positioned on the right lower extremity, the knee angle was measured prior to the completion of the first effort.

4. A 50-second rest period followed.

5. The procedure was repeated until ten contractions had been performed.

Group III - Monopolar Electrical Muscle Stimulation Concurrent with Isometric Quadriceps Exercise

1. The subject assumed the treatment position.

2. The treatment routine for electrical muscle stimulation concurrent with isometric quadriceps exercise was conducted.

3. The active electrode plate (6 cm x 8 cm) and sponge pad (7 cm x 9 cm) were placed over the motor point (54) of the vastus medialis, and securely fastened in position with an elastic wrap (Figures 9 and 10).

4. The dispersive electrode plate (8.5 cm x 11.5 cm) and sponge pad (9.5 cm x 12.5 cm) were placed over the femoral nerve in the femoral triangle, and securely fastened in position with an elastic wrap (Figures 9 and 10).

Group IV - Bipolar Electrical Muscle Stimulation Concurrent with Isometric Quadriceps Exercise

1. The subject assumed the treatment position.

2. The treatment routine for electrical muscle stimulation concurrent with isometric quadriceps exercise was conducted.

3. The active electrode plate (6 cm x 8 cm) and sponge pad (7 cm x 9 cm) were placed over the distal aspect of vastus medialis, and securely fastened in position with an elastic wrap (Figures 11 and 12).

4. The dispersive electrode plate (6 cm x 8 cm) and sponge pad (7 cm x 9 cm) were placed over the proximal aspect of vastus medialis, and securely fastened (Figures 11 and 12)

All subjects were asked to verbally indicate to the investigator when they were capable of withstanding a greater intensity of current, and also when the new maximal level of tolerance had been reached. Levels of current intensity were subjectively determined, but remained maximal for the individual. The concept of 'maximal'

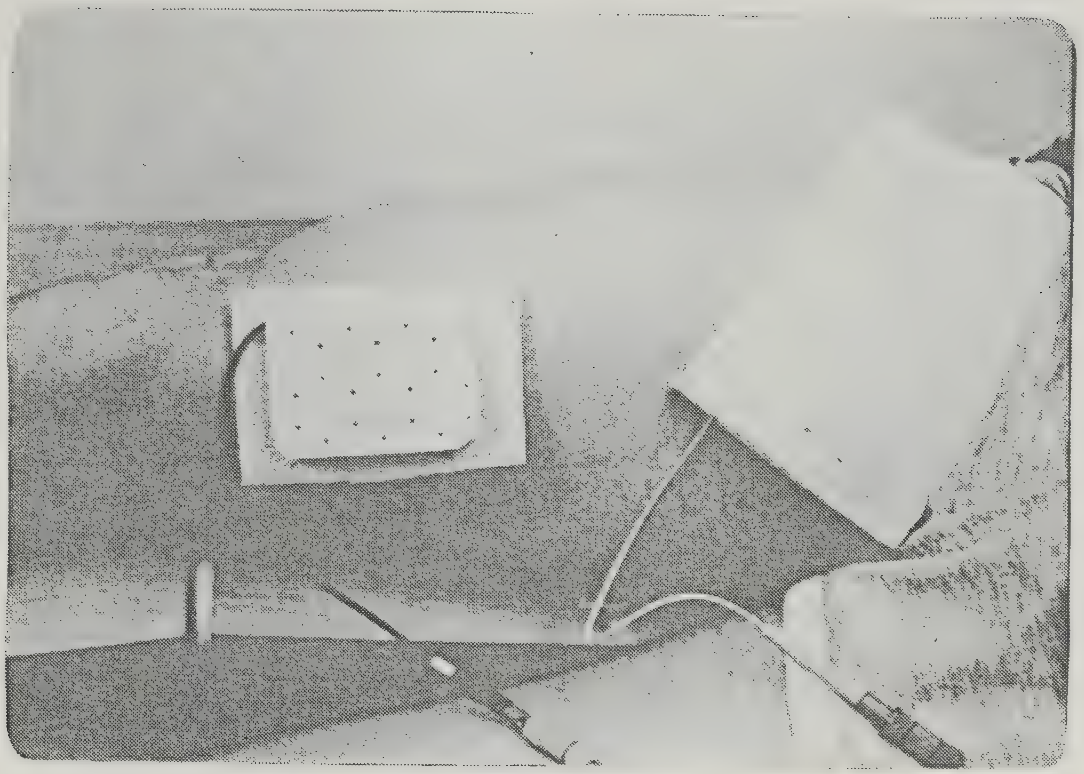

Figure 9

Electrode Placement for Monopolar Technique

Figure 10

Electrode Placement Secured by Elastic Wraps

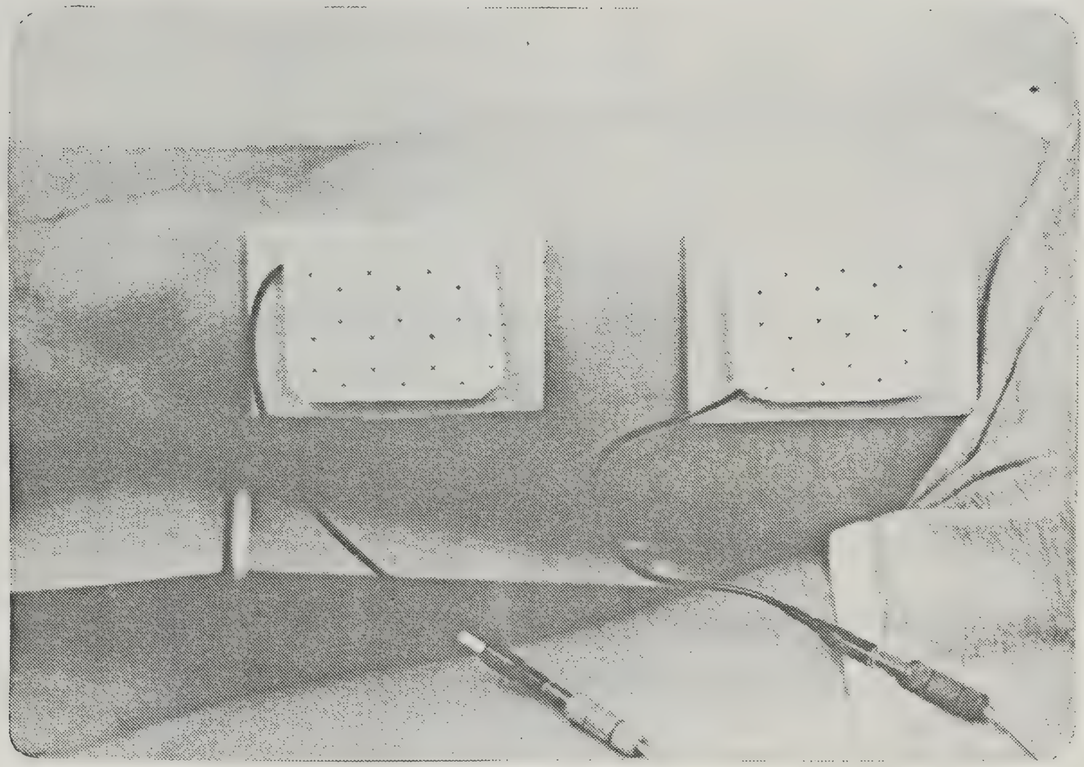

Figure 11
Electrode Placement for Bipolar Technique

Figure 12
Electrode Placement Secured by Elastic Wraps

bordered on being intolerable.

Statistical Analysis

The statistical analysis used was a two-factor (treatment by occasion) multivariate analysis of variance (MANOVA) with the occasion factor being treated as the repeated measure (68).

The main treatment effects were calculated for the girth measurements and the isokinetic measurements (variables 1 to 5 as described in Appendix E), taken simultaneously. The main treatment effects were calculated on the isometric measurements (variables 6 to 9 as described in Appendix E), taken simultaneously. The post-hoc Helmert contrasts (group n versus the average of the remaining n-1 groups) were calculated on variables 1 to 5 taken simultaneously, and variables 6 to 9 taken simultaneously. The orthogonal Helmert contrasts were followed by the non-orthogonal pair-wise contrasts calculated on all possible pairs of groups for variables 1 to 5 taken simultaneously, and variables 6 to 9 taken simultaneously. Following calculation of the main treatment effects, the main occasion effects were calculated for variables 1 to 5 taken simultaneously, and variables 6 to 9 taken simultaneously.

The main treatment effects were calculated on the two girth measurements, three isokinetic measurements, and four isometric measurements (nine variables), taken individually. The post-hoc Helmert contrasts and pair-wise

contrasts were calculated on all variables, taken individually. Following calculation of the main treatment effects on individual variables, the main occasion effects were calculated for all variables, taken individually.

The interaction effects were calculated for variables 1 to 5 taken simultaneously, and variables 6 to 9 taken simultaneously. The interaction effects for all groups taken simultaneously, and all possible pairs of groups were reported. Where significance was observed, the interaction effects were calculated on individual variables. The interaction effects for all groups taken simultaneously were reported. Where significance was observed, the interaction effects for all possible pairs of groups were reported.

Throughout the statistical analysis, the .05 level of significance was used. Probabilities of $.05 \geq p \leq .01$ were reported as they occurred. All other probabilities were reported as either $p > .05$ or $p < .01$. Raos approximate F-test using Wilks Lambda was used to calculate the F-ratio. Where necessary, critical values of F were interpolated.

CHAPTER IV

RESULTS AND DISCUSSION

Results

The following terminology (Appendix E) was used throughout the results and discussion:

variable 1 : girth at 77.5% (cm)

variable 2 : girth at 50.0% (cm)

variable 3 : dynamic strength (ft lbs)

variable 4 : muscular power (ft lbs)

variable 5 : muscular endurance (sec)

variable 6 : isometric strength -15° (ft lbs)

variable 7 : isometric strength -30° (ft lbs)

variable 8 : isometric strength -45° (ft lbs)

variable 9 : isometric strength -60° (ft lbs)

The statistical analyses of the data collected for twenty-one male volunteers (ranging from 18 to 35 years, mean age of 23.8 years) may be found in Appendices F to J.

Appendix F illustrates the group means for pre and post-treatment measures, for each variable. Also included are the treatment mean differences on pre and post-treatment measures for each group, for each variable.

Appendix G illustrates the results of the two-way MANOVA with repeated measures on variables 1 to 5 taken simultaneously, and variables 6 to 9 taken simultaneously. Also included are the results of the post-hoc contrasts.

Appendix H illustrates the results of the two-way

MANOVA with repeated measures for all variables, taken individually. Also included are the results of the post-hoc contrasts.

Appendix I illustrates the MANOVA interaction effects for all groups for variables 1 to 5 taken simultaneously, and variables 6 to 9 taken simultaneously.

Appendix J illustrates the MANOVA interaction effects for all groups on individual variables.

The treatment means for each group on each occasion for each variable may be found on Table 1. Table 2 summarizes the treatment mean differences on occasion for each group on each variable.

Variables 1 to 5

a) Main Group Effects for Variables 1 to 5 Taken Simultaneously

A significant treatment effect (df=15,44.6; F=9.82; $p<.01$) was observed when all groups were contrasted simultaneously on the means of variables 1 to 5 (Table 3, Figure 13). All Helmert contrasts for group effects (Table 7) were statistically significant ($p<.01$). Thus, a general treatment effect was observed when the vector of averaged means for groups II, III, and IV was contrasted to the mean vector for group I. A significant treatment effect ($p<.01$) was observed when the means vector for group II was contrasted to the vector of averaged means for groups III and IV. A final contrast of the means

Figure 13

Mean Group Effects Averaged Over Occasion for Variables 1 to 5

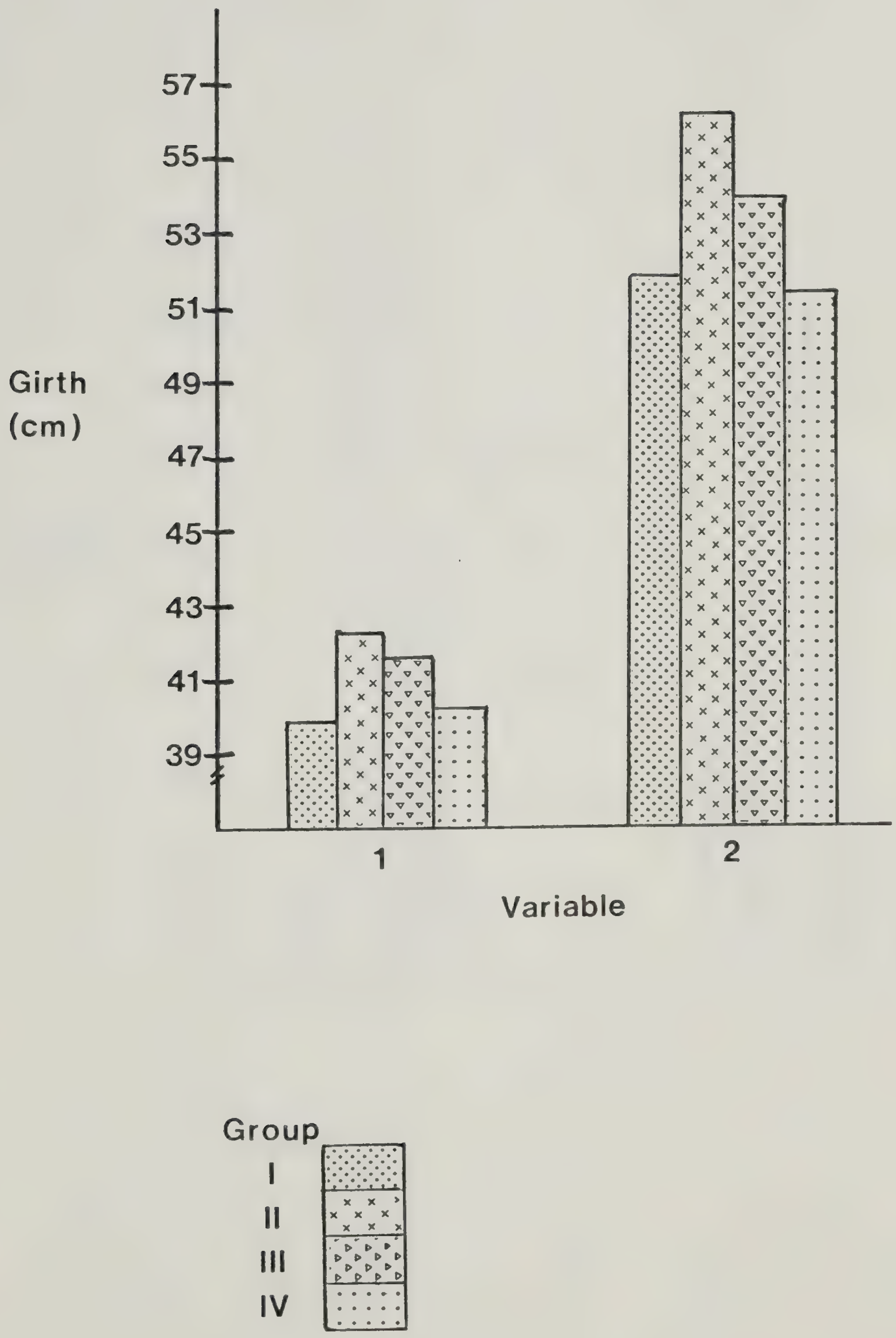

Figure 13
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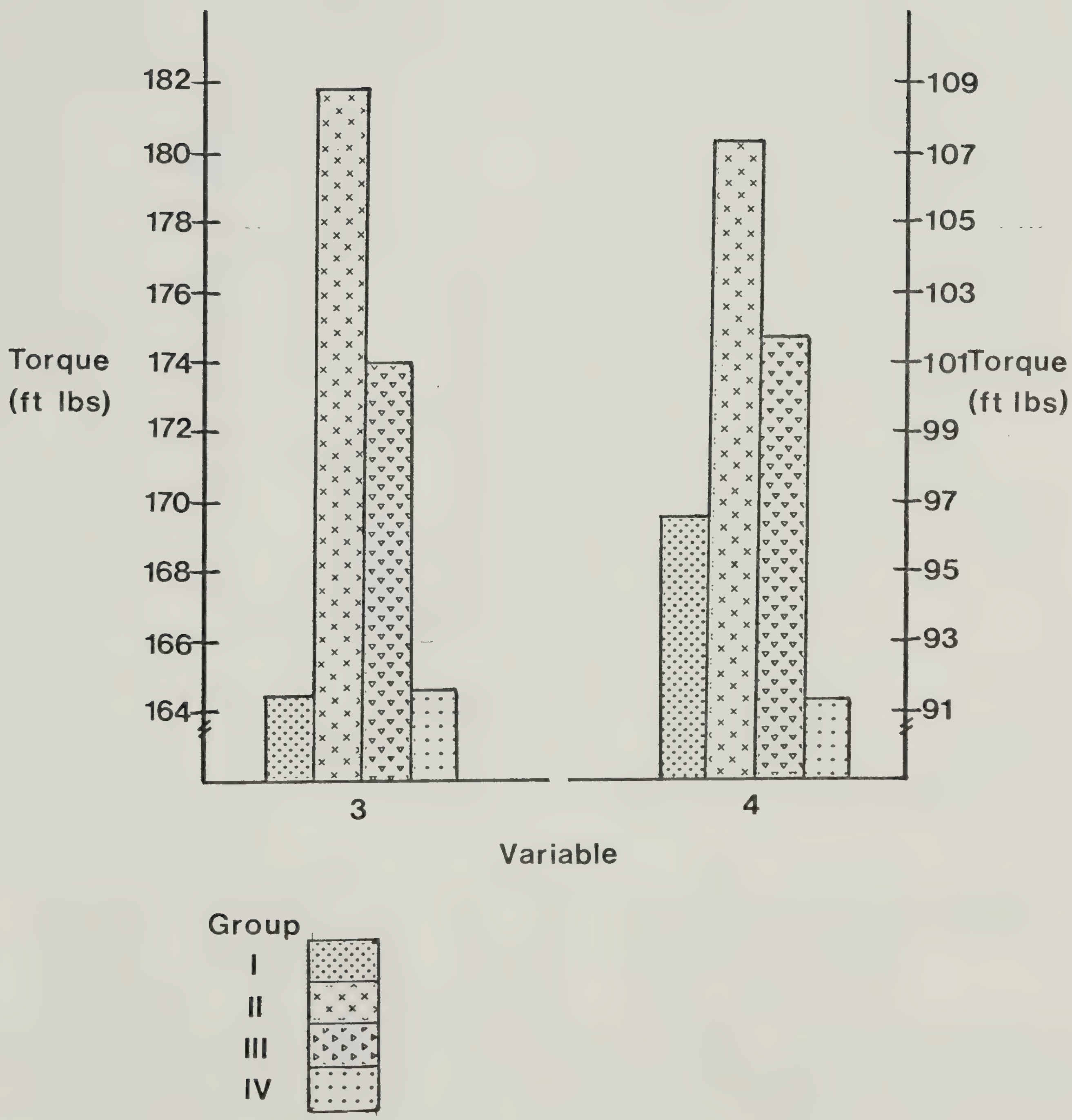

Figure 13
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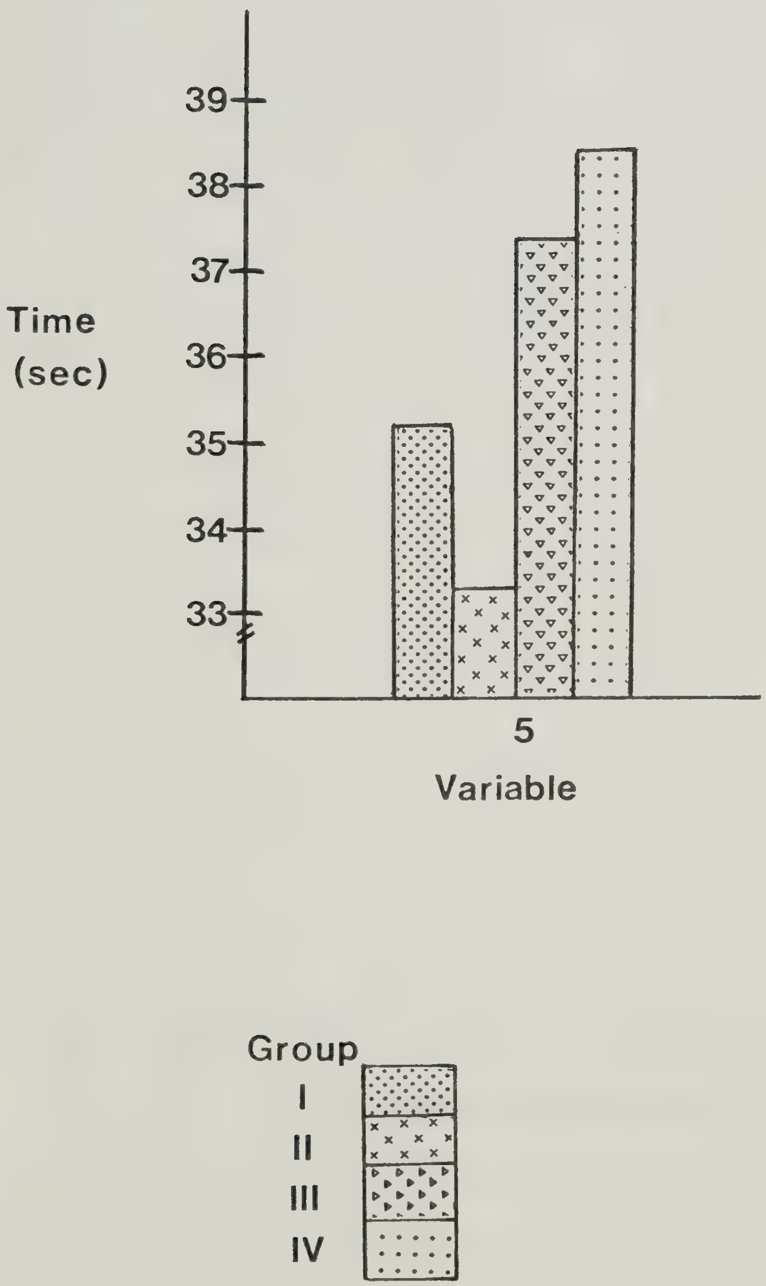

vector for groups III and IV was observed to be significant ($p<.01$). All pair-wise contrasts of the group means vectors (Table 7) were statistically significant ($p<.01$). Thus, the means vector for each group could not be considered as having come from a common population.

b) <u>Individual Variable Effects for Variables 1 to 5</u>

Table 9 illustrates the mean group effects for the individual variables. Variables 1 to 5, taken individually, all demonstrated significant treatment effects ($p<.01$). The largest F-ratios were observed for variable 1 (df=3,20; F=26.63), variable 2 (df=3,20; F=22.55), and variable 4 (df=3,20; F=21.61).

For variable 1 (Table 10), a treatment effect ($p<.01$) was observed for all Helmert contrasts. Group I contrasted to group IV was the only non-significant (p .05) pair-wise contrast. With the exception of groups I and IV, group means on variable 1 could not be considered as having come from a common population.

For variable 2 (Table 11), a treatment effect (p .01) was observed for all Helmert contrasts. Group I contrasted to group IV was the only non-significant ($p>.05$) pair-wise contrast. With the exception of groups I and IV, group means on variable 2 could not be consdered as having come from a common population.

For variable 3 (Table 12), a treatment effect ($p<.01$) was observed for all Helmert contrasts. Group I contrasted

to group IV was the only non-significant ($p > .05$) pair-wise contrast. With the exception of groups I and IV, group means on variable 3 could not be considered as having come from a common population.

For variable 4 (Table 13), no significant difference ($p > .05$) between group I and the average of groups II, III and IV was observed. Thus, the averaged group means for groups II, III and IV could be considered to be equal to the mean of group I in the population. The remaining Helmert contrasts were significant ($p < .01$). A comparison of the averaged group means for groups III and IV could be considered significantly different in the population than the mean of group II. Furthermore, the means of groups III and IV were not considered as being equal in the population. Significant treatment effects ($p \leq .02$) were observed between all pairs of means for groups contrasted. Group means were thus considered as being unequal to each other in the population.

For variable 5 (Table 14), a treatment effect ($p < .01$) was observed when the mean of group II was contrasted to the averaged mean for groups III and IV. The respective means could not be considered as being equal in the population. A level of non-significant ($p > .05$) was observed for the remaining Helmert contrasts. Significant ($p < .01$) pair-wise contrasts were observed for groups I and III, I and IV, II and III, and II and IV. Thus, the significant pair-wise contrasts of group means could not be considered as

being equal in the population.

c) <u>Main Occasion Effects for Variables 1 to 5 Taken Simultaneously</u>

Table 5 illustrates the significant treatment effect (df=5,16; F=10.85; $p<.01$) for the means for the pre and post-treatment effects, averaged over the groups for variables 1 to 5, taken simultaneously. Thus, the comparison of the pre and post-treatment means for variables 1 to 5, taken simultaneously, was significant, and they were not considered equal in the population. All variables were observed to have higher post-treatment measures (Figure 14).

d) <u>Individual Variable Effects for Variables 1 to 5</u>

Table 9 illustrates the pre and post-treatment effects for the individual variables. Variable 2 was the only non-significant ($p>.05$) variable. The largest F-ratios were observed for variable 5 (df=1,20; F=34.61), and variable 4 (df=1,20; F=34.60).

A significant overall interaction effect (df=15,39; F=2.11; p=0.03) was observed, illustrating changes between the pre and post-treatment measures for variables 1 to 5 taken simultaneously across all groups, were not equal (Table 19). The pre and post-treatment interaction effects between group pairs on variables 1 to 5 taken simultaneously, differed. Significant interactions ($p\leq.03$) were observed between groups I and IV, II and IV, and III

Figure 14
Mean Occasion Effects Averaged Over
Groups for Variables 1 to 5

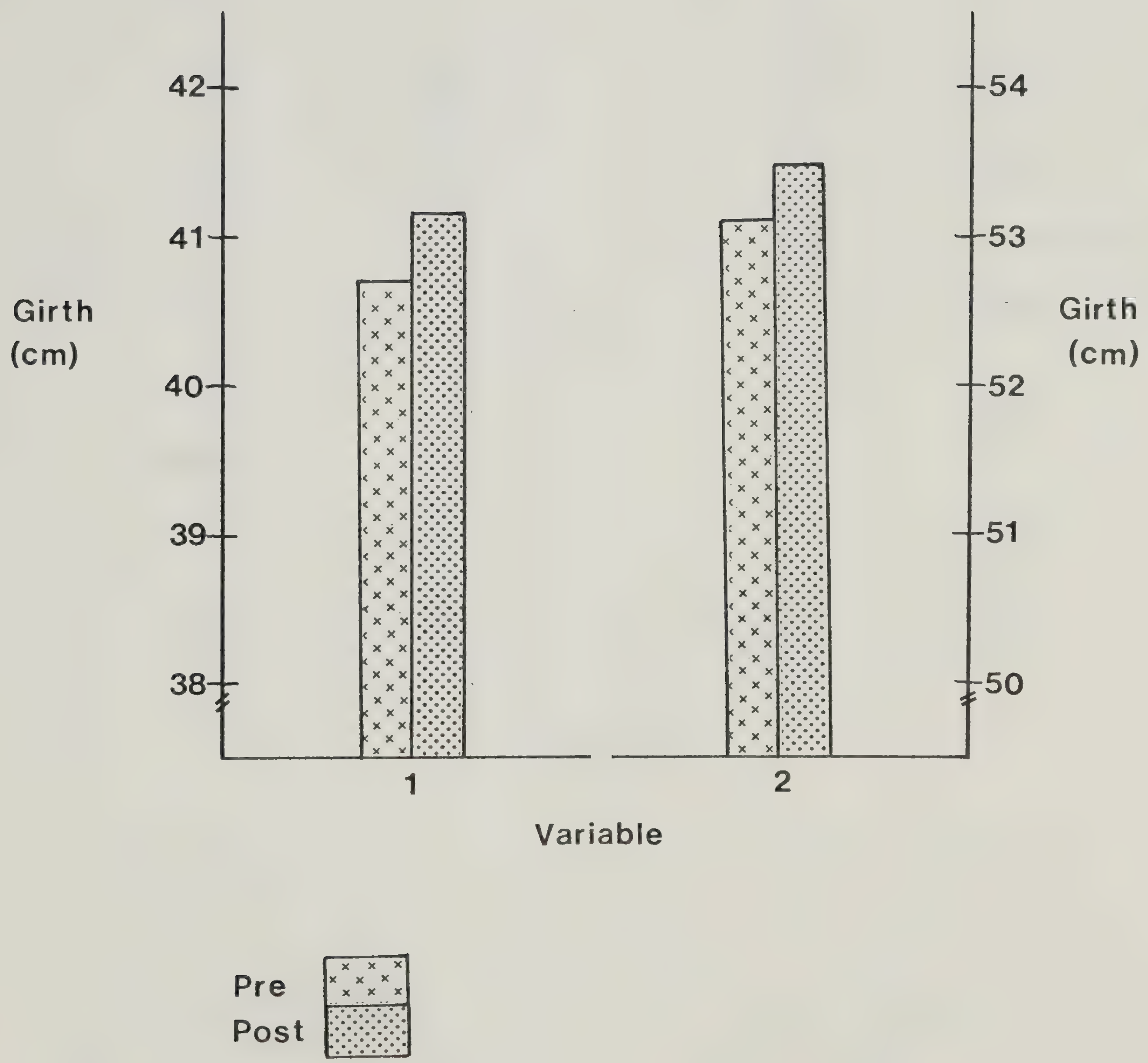

Figure 14
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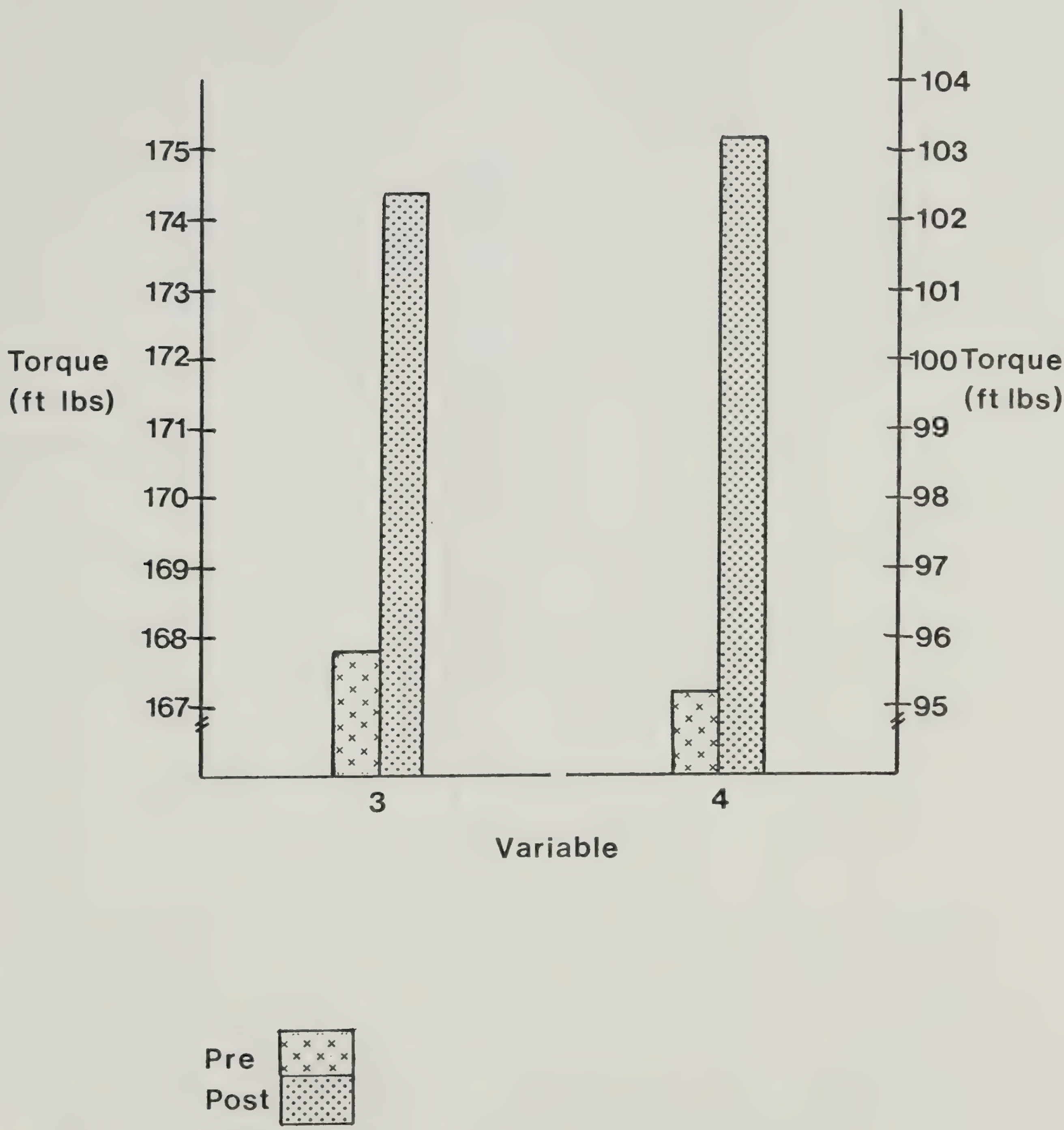

Figure 14
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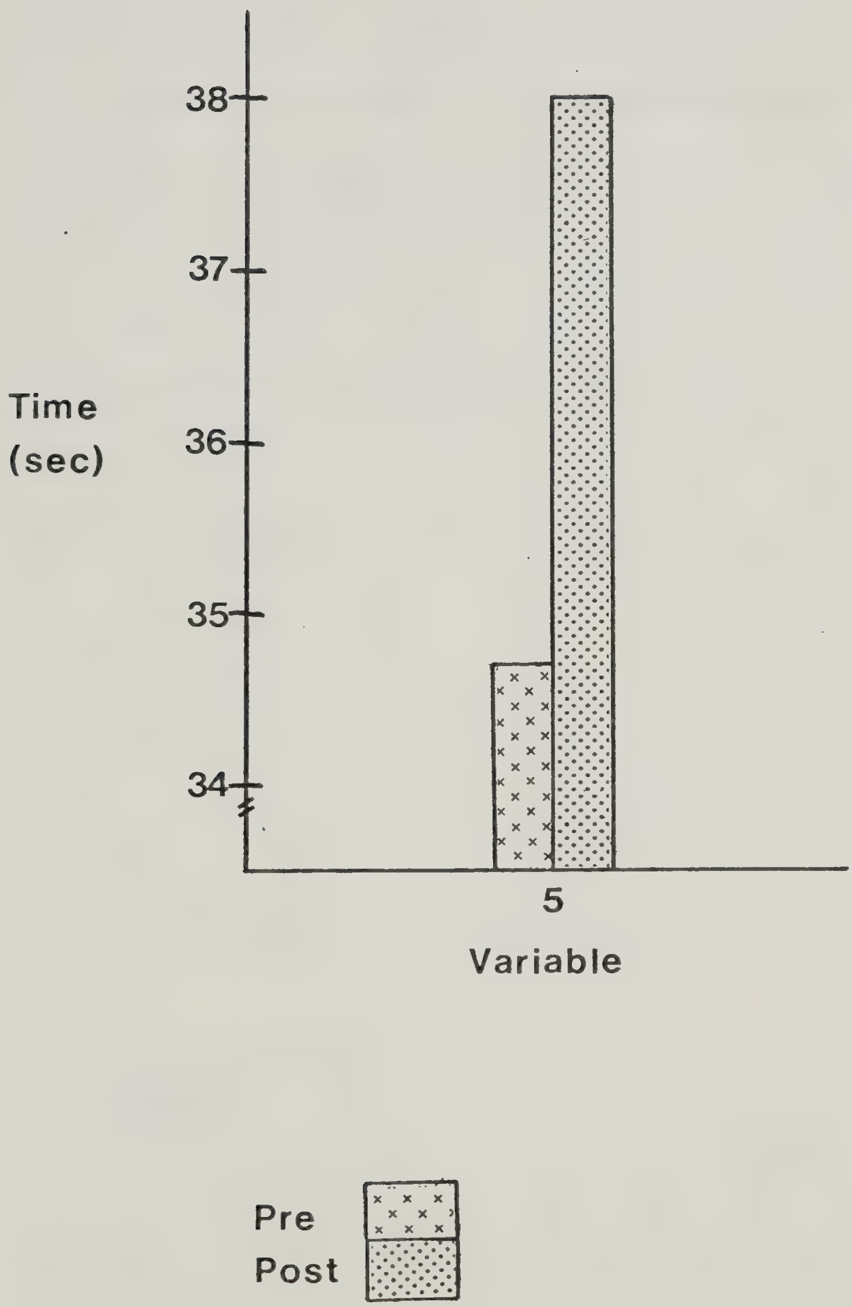


and IV, implying a lack of parallelism between the pre and post-treatment comparisons. The largest F-ratio (df=5,14; F=7.70) was observed for the interaction of groups III and IV, when variables 1 to 5 were taken simultaneously.

The interaction effects were calculated on the individual variables 1 to 5. When all groups were taken simultaneously, the interaction effects for variables 1, 2 and 3 were not observed to be significant ($p > .05$). When all groups were taken simultaneously on variable 4, the interaction effect was observed to be significant ($p=0.01$). The group pair interaction effects were observed to be significant for groups I and III ($p=0.02$), I and IV ($p < .01$), and II and IV ($p=0.04$). The largest F-ratio (df=1,17; F=11.98), was observed between groups I and IV.

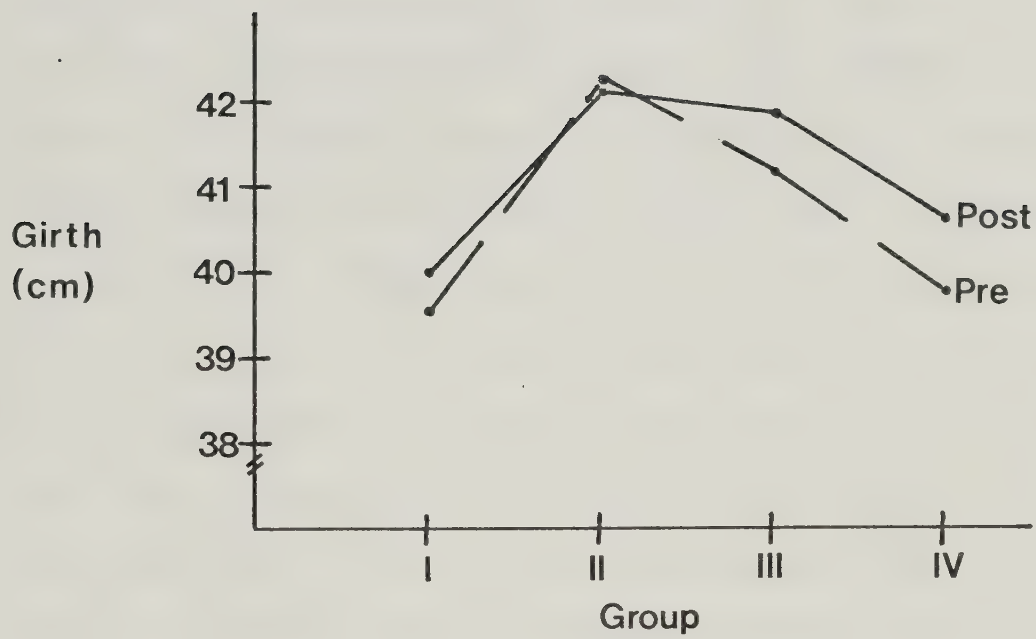
For variable 5, the interaction effect when all groups were taken simultaneously, was observed to be significant ($p=0.01$). The group pair interaction effects were observed to be significant for groups I and III ($p=0.01$), and I and IV ($p < .01$). The largest F-ratio (df=1,17; F=14.08) was observed between groups I and IV.

e) Graphical Results for Variables 1 to 5 Taken Individually

For variable 1 (Figure 15), group IV was observed to demonstrate the greatest change with treatment (0.92 cm). As a consequence of the low pre-treatment value, the increment with training for group IV was not enough to raise the treatment effect to the average over occasion

Figure 15

Group Means on Occasion for Variable I



for groups II and III. Although the pre-treatment difference for groups II and III (favoring group II) was 1.01 cm, the post-treatment difference (favoring group II) was only 0.35 cm. Group III increased girth at 77.5% approximately 0.5 cm with training, whereas group II demonstrated little change. Although changes occurred with training, lack of statistical significance was observed.

For variable 2 (Figure 16), group IV was observed to demonstrate the greatest change with treatment (2.12 cm). The lowest pre-treatment measure and highest standard deviation were also observed to characterize group IV. Although group IV was observed to increase considerably with treatment, the change was not enough to increase the performance of group IV to be significant when contrasted to the average means on occasion for groups II and III. In fact, the average over occasion for group IV, with training, approximated the average mean over occasion for group I. Groups II and III were observed to decrease 0.63 cm and 0.20 cm respectively, after treatment.

For variable 3 (Figure 17), group II was observed to have the greatest change (11.25 ft lbs) with treatment, despite having the highest pre-treatment measure. Groups III and IV were observed to change the least (5.00 ft lbs and 1.16 ft lbs respectively) with treatment.

For variable 4 (Figure 18), group IV was observed to demonstrate the greatest change (13.33 ft lbs) after treatment, but also had the lowest pre-treatment measure

Figure 16

Group Means on Occasion for Variable 2

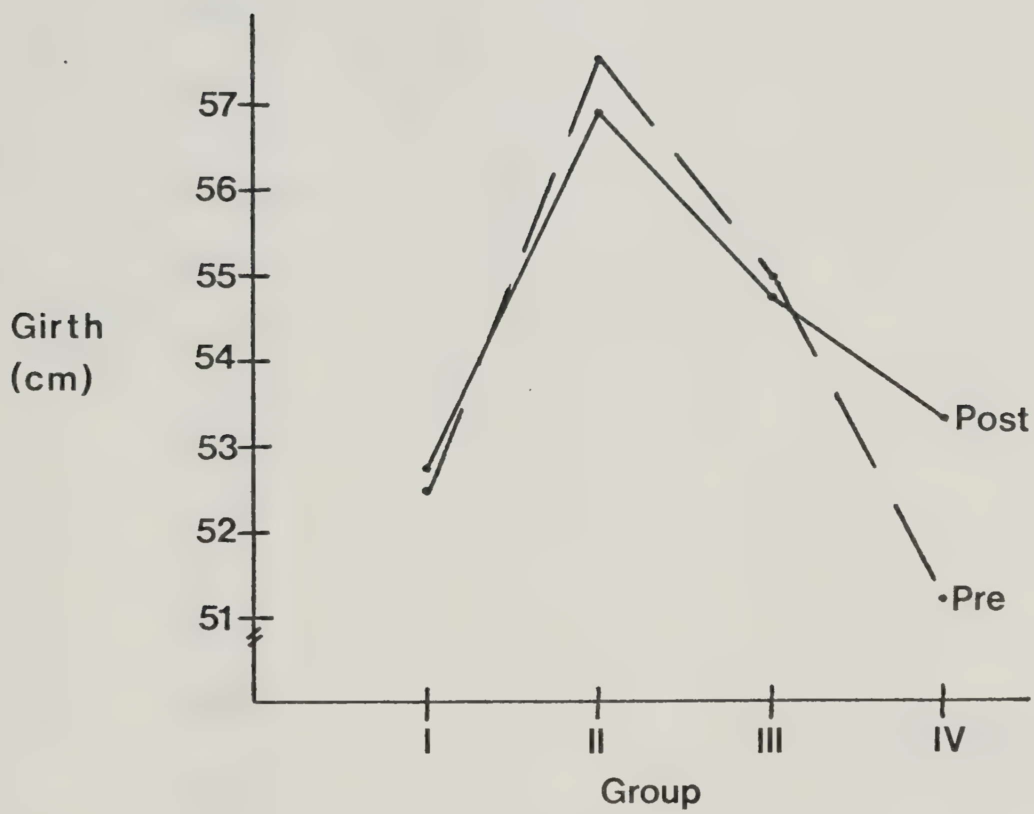


Figure 17
Group Means on Occasion for Variable 3

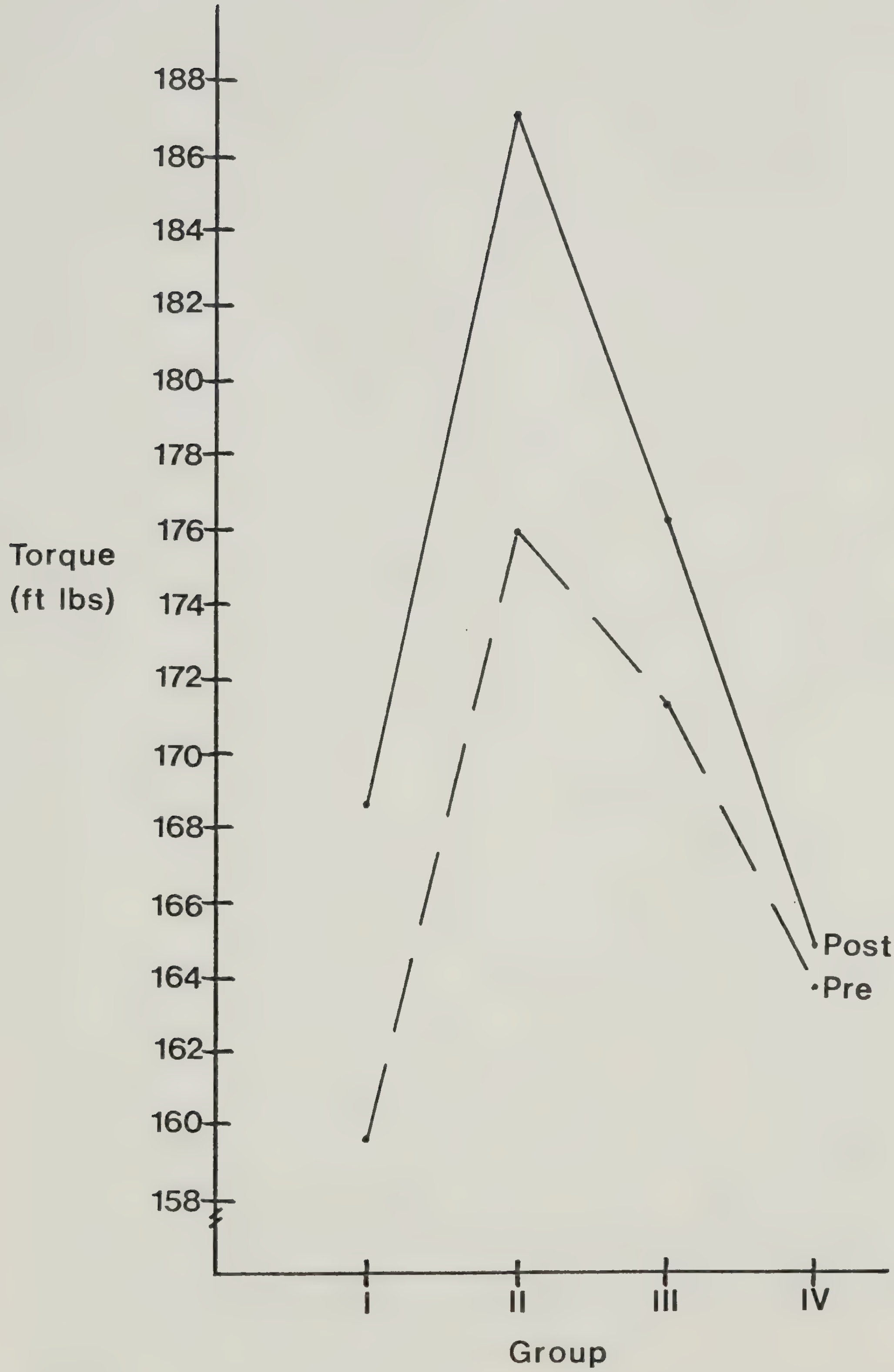
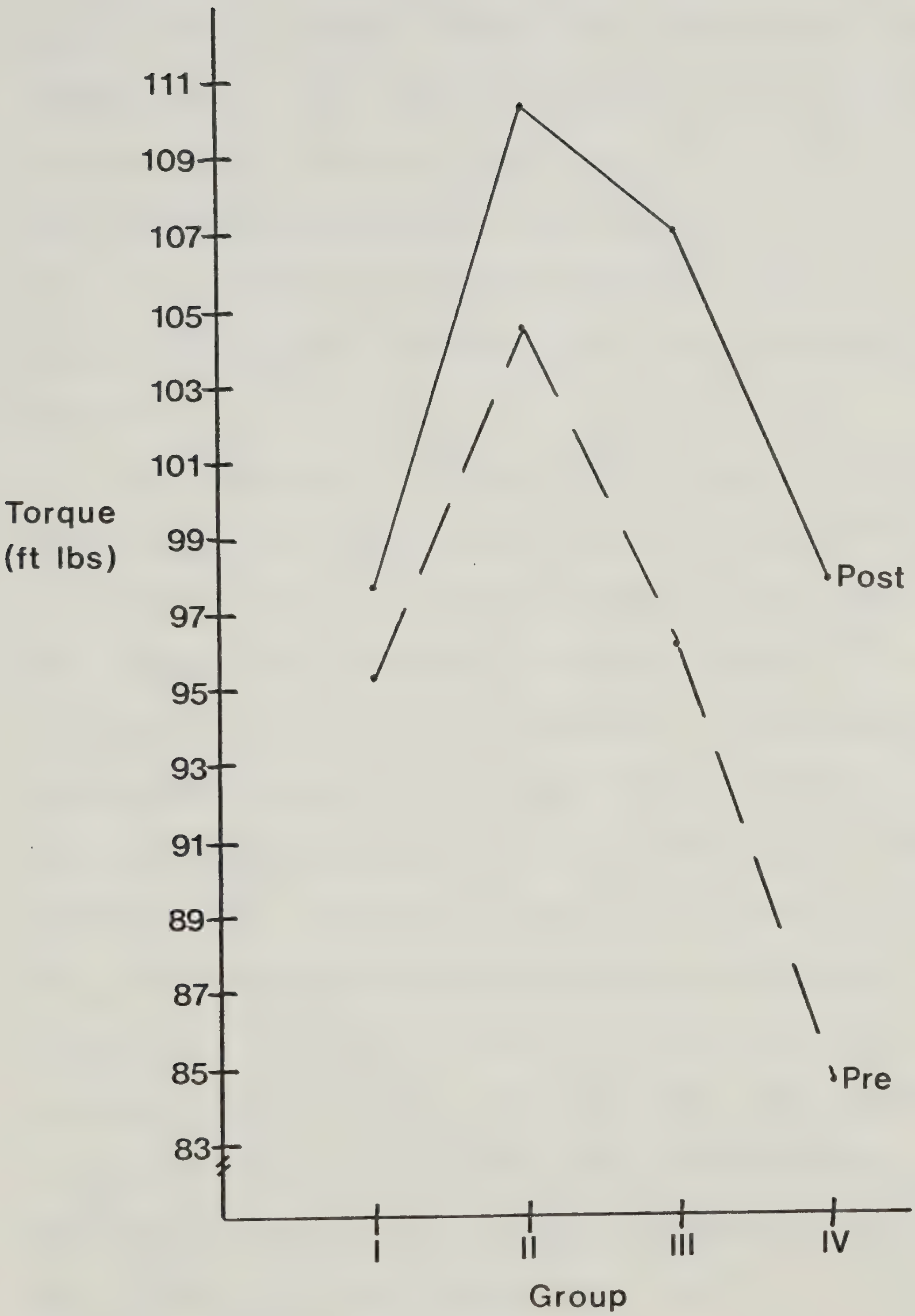


Figure 18

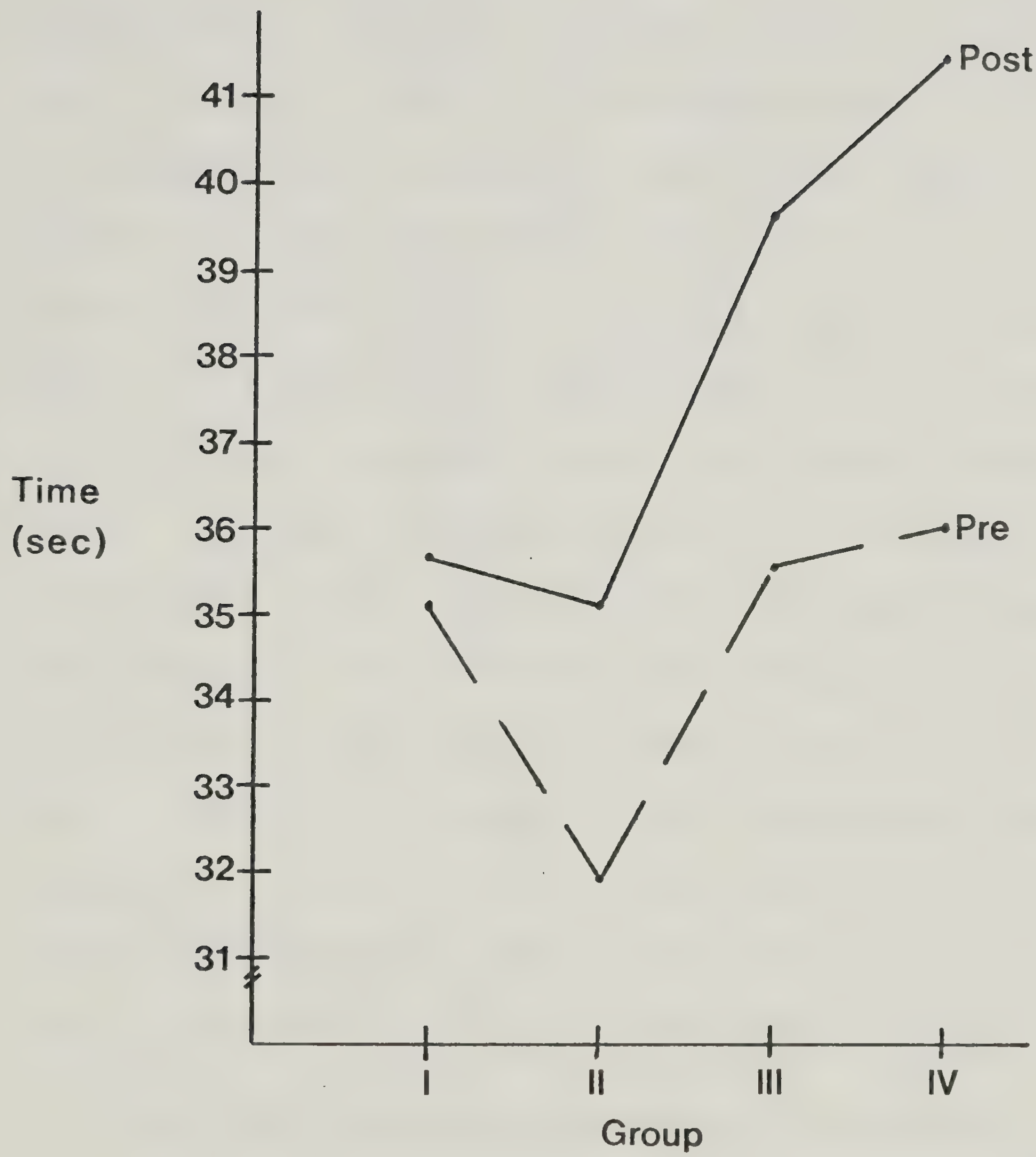
Group Means on Occasion for Variable 4



of all the groups. Group III was observed to change 10.83 ft lbs, with training. As a consequence of the low pre-treatment measure for group IV, the change over occasion approached the change over occasion for group I. The change, with training, for group IV was not enough to increase the treatment effects to the average levels for groups II or III. Although groups I and III differed by only 0.77 ft lbs (favoring group III) on the pre-treatment measures, the difference increased to 9.40 ft lbs (favoring group III) on the post-treatment measures. Thus, variable 4 showed the most consistent changes over the groups.

For variable 5 (Figure 19), group IV was observed to demonstrate the greatest pre and post-treatment difference (5.40 sec) of all the groups, even though demonstrating the highest pre-treatment measure. Group III was observed to change 4.08 sec, with training. The lowest pre-treatment measure (31.95 sec) was observed for group II. The pre-treatment measures for groups I, III and IV were similar, and differed at most by 0.93 sec (group IV - I). The post-treatment difference between groups I and III increased to 3.97 sec (Group III - I), and 5.77 sec for groups I and IV (group IV - I). The pre-treatment difference between groups III and IV was 0.48 sec (group IV - III) while the post-treatment difference for groups III and IV was 1.80 sec (group IV - III).

Figure 19
Group Means on Occasion for Variable 5



Variables 6 to 9

a) Main Group Effects for Variables 6 to 9 Taken Simultaneously

A significant treatment effect (df=12,45.3; F=2.95; $p<.01$) was observed when all groups were contrasted simultaneously on the means of variables 6 to 9 (Table 4, Figure 20). A general treatment effect ($p=0.02$) was observed when the vector of averaged means for groups II, III and IV was contrasted to the mean vector for group I (Table 8). When the means vector for group II was contrasted to the vector of averaged means for groups III and IV, a level of non-significance ($p>.05$) resulted and could be considered as having come from a common population. The final Helmert contrast of the means vectors for groups III and IV was observed to be significant ($p<.01$) and could not be considered as having come from a common population. Pair-wise contrasts of group means vectors were observed to be significant for groups I and II ($p<.01$), II and IV ($p=0.05$), and III and IV ($p<.01$). The groups demonstrating significant pair-wise contrasts could not be considered as having come from a common population.

b) Individual Variable Effects for Variables 6 to 9

Table 9 illustrates the mean group effects for individual variables. Variables 7 and 8, taken individually, were observed to have significant treatment effects ($p\leq.02$), whereas variables 6 and 9, taken individually, were observed to have no treatment effect ($p>.05$). The

Figure 20
Mean Group Effects Averaged Over
Occasion for Variables 6 to 9

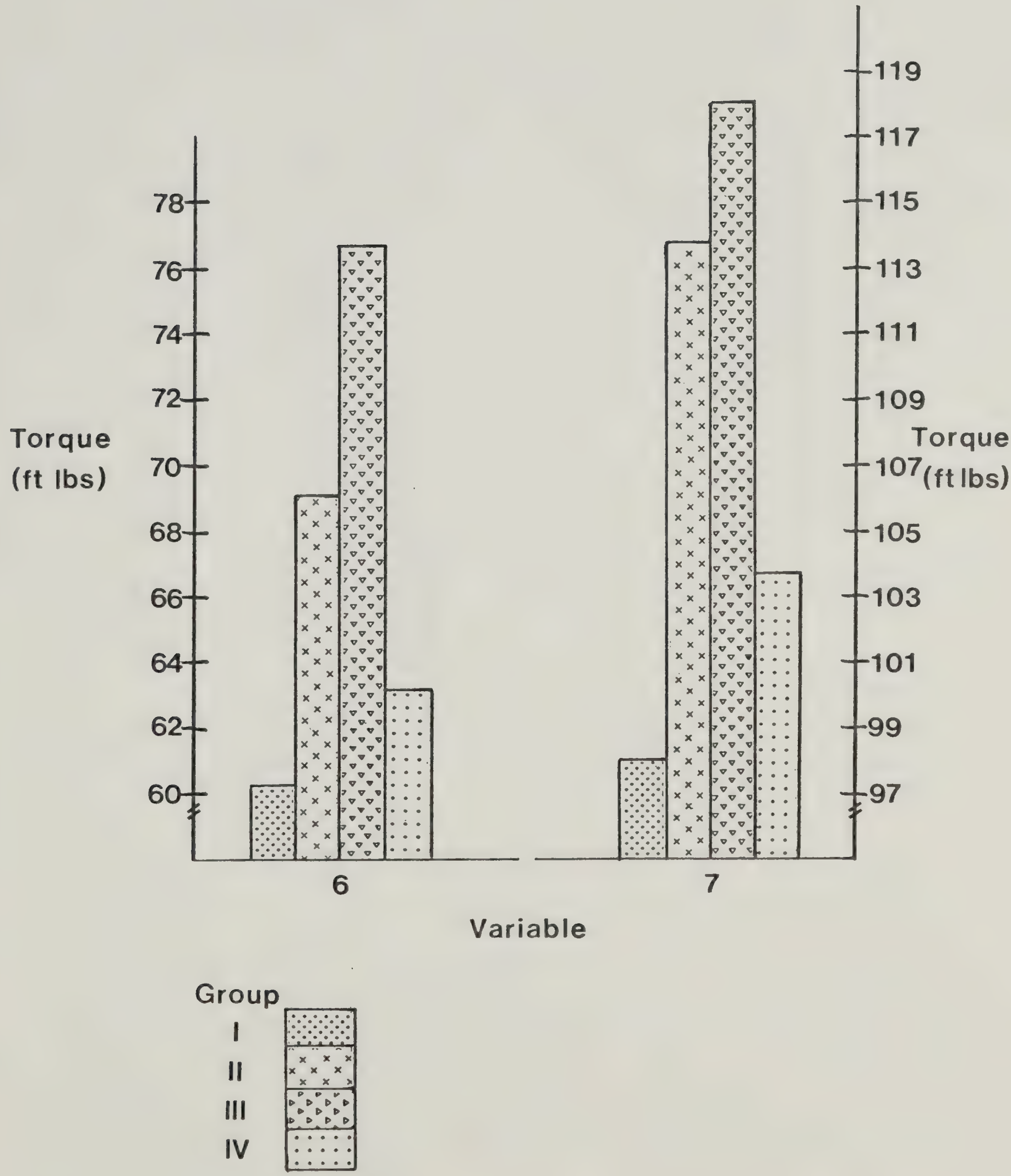


Figure 20
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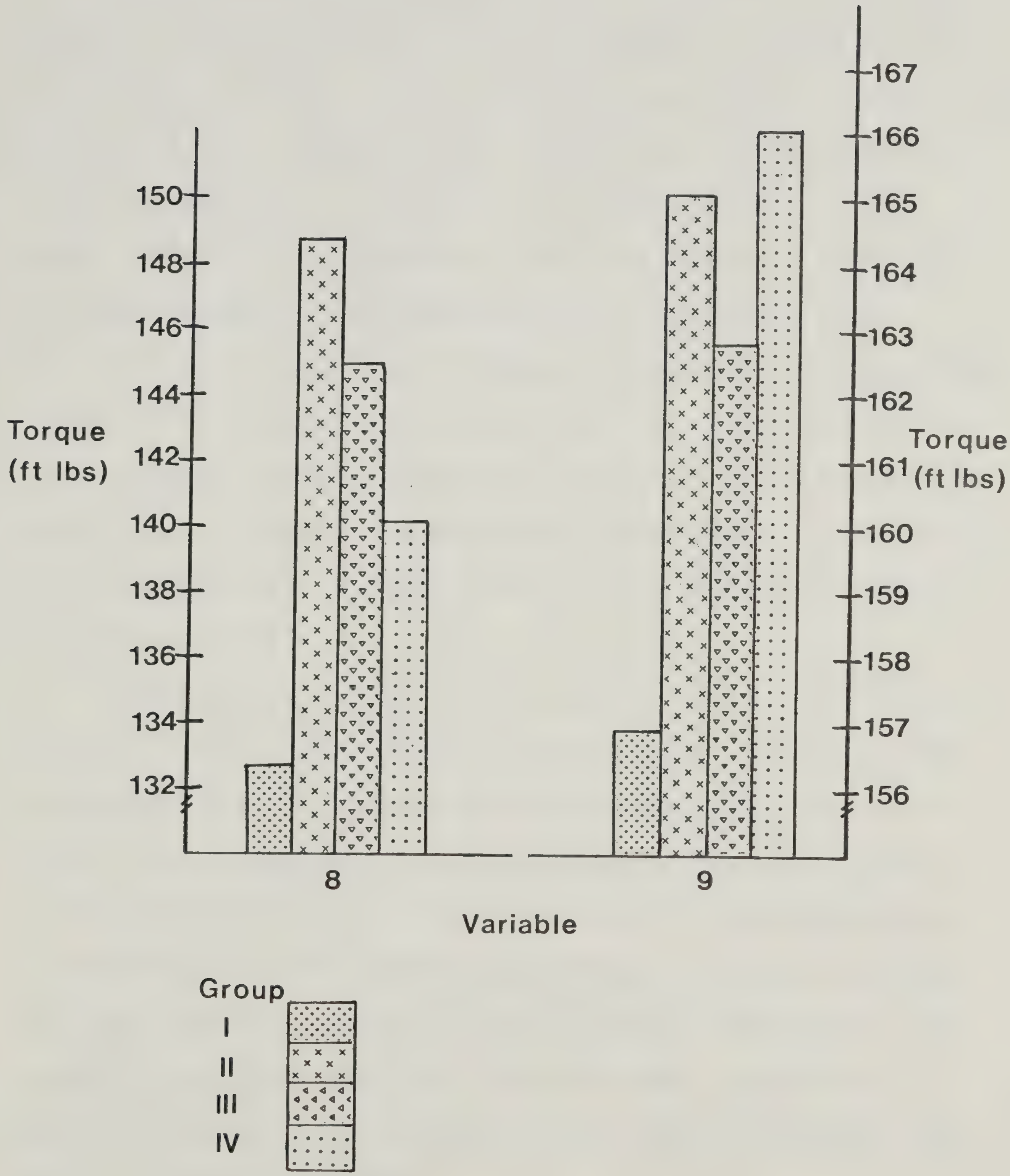


largest F-ratio was observed for variable 7 ($df=3,20$; $F=10.30$), which was also identical to the angle of training. The smallest F-ratio was observed for variable 6 ($df=3,20$; $F=0.75$).

For variable 7 (Table 16), a significant difference ($p<.01$) between group I and the average of groups II, III and IV was observed. Thus, the averaged group means for groups II, III, and IV could not be considered as being equal to the mean of group I, in the population. The mean for group II contrasted with the averaged mean for groups III and IV was observed to be non-significant ($p>.05$). A contrasting of means for groups III and IV was observed to be significant ($p<.01$). With the exception of pair-wise contrasts between groups II and III ($p>.05$), and I and IV ($p>.05$), group means on variable 7 could not be considered to be equal ($p\leq.03$), nor having come from a common population.

For variable 8 (Table 17), a significant treatment effect ($p<.01$) was observed when the mean for group I was contrasted to the average mean for groups II, III and IV. Thus, the groups were not considered to have come from a common population. All remaining Helmert contrasts were observed to be non-significant ($p>.05$). Thus, a contrast of the means for group III and IV, and a contrast of the mean for group II with the averaged mean for groups III and IV could be considered as being equal and having come from a common population.

c) <u>Main Occasion Effects for Variables 6 to 9 Taken Simultaneously</u>

Table 6 illustrates the significant occasion effect (df=4,17; F=3.34; p=0.03) for the means for the pre and post-treatment effects, averaged over the groups for variables 6 to 9, taken simultaneously. Thus, the comparison of the pre and post-treatment means for variables 6 to 9 could not be considered equal in the population. All variables were observed to have higher post-treatment measures (Figure 21).

d) <u>Individual Variable Effects for Variables 6 to 9</u>

Table 9 illustrates the pre and post-treatment effects for the individual variables. Variable 6 was the only non-significant ($p > .05$) variable. The largest F-ratio was observed for variable 7 (df=1,20; F=13.58; $p < .01$), the angle of training.

The overall interaction effect (df=12,40; F=0.71; $p > .05$) was not observed to be significant, indicating that changes between the pre and post-treatment measures were not different for the groups, when variables 6 to 9 were taken simultaneously (Table 20). As such, the interaction effects between group pairs were observed to be non-significant ($p > .05$). Thus, changes between the pre and post-treatment measures for groups could be considered as being equal.

Figure 21

Mean Occasion Effects Averaged Over Groups for Variables 6 to 9

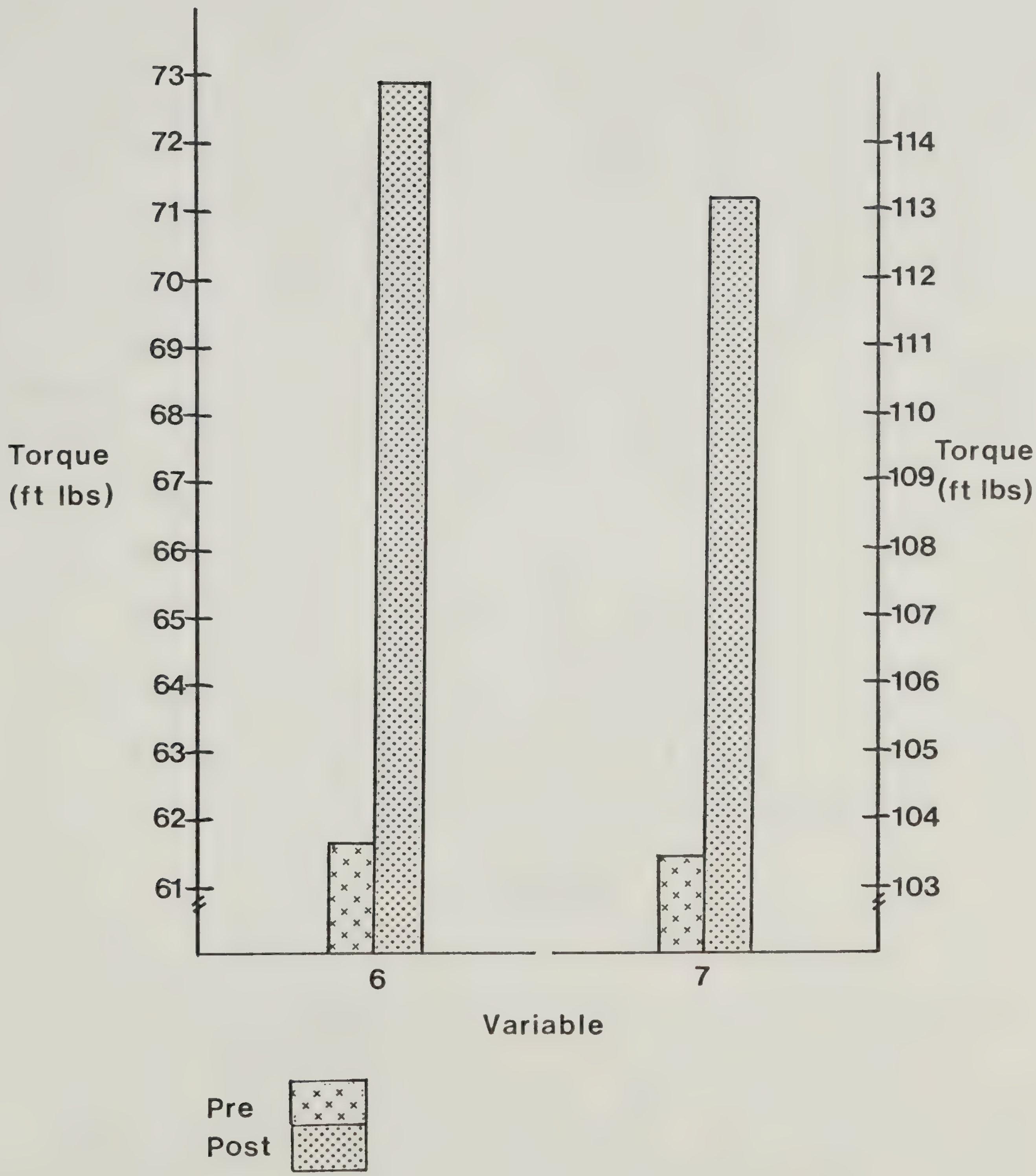
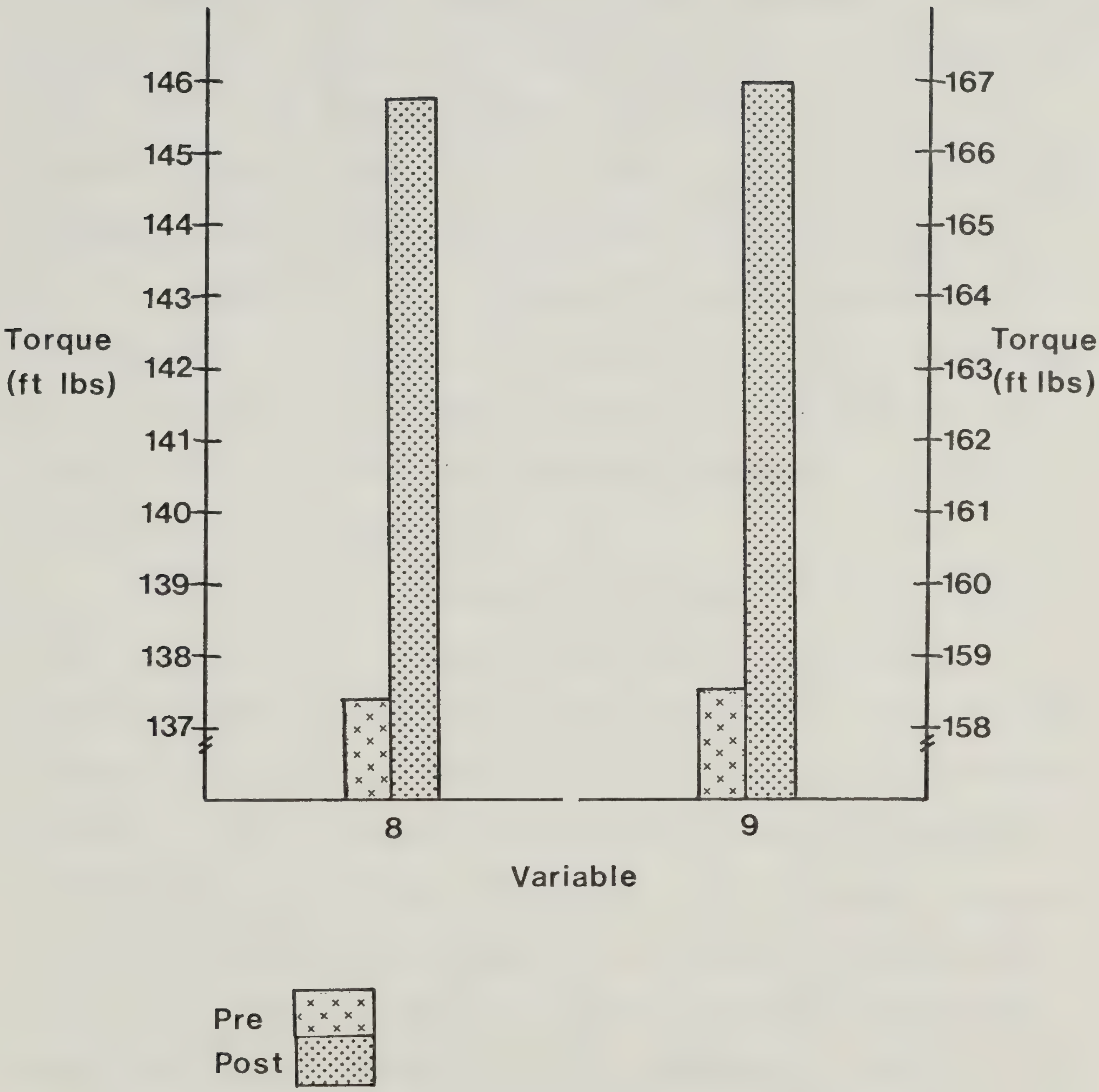


Figure 21
cont'd



e) <u>Graphical Results for Variables 6 to 9 Taken Individually</u>

For variable 6 (Figure 22), groups III and IV were observed to have the greatest changes for pre and post-treatment measures (group III = 16.34 ft lbs; group IV = 17.00 ft lbs). Group IV was also observed to have the lowest pre-treatment measure. The pre-treatment average difference for groups III and IV was 13.66 ft lbs (group III - IV). The post-treatment average difference for groups III and IV was 13.00 ft lbs (group III - IV). For groups II and IV, the pre-treatment difference was 8.58 ft lbs (group II - IV), whereas the post-treatment difference was only 3.08 ft lbs (group II - IV). For groups II and III the pre-treatment difference was 5.08 ft lbs (group III - II), whereas the post-treatment difference was 9.92 ft lbs (group III - II).

For variable 7 (Figure 23), groups III and IV were observed to have the greatest pre and post-treatment change (group III = 15.83 ft lbs; group IV = 18.34 ft lbs). Group IV was also observed to have the lowest pre-treatment measure. The pre-treatment difference between groups II and III was 0.25 ft lbs (group III - II), whereas the post-treatment difference increased to 8.33 ft lbs (group III - II). For groups II and IV, the pre-treatment difference was 15.42 ft lbs (group II - IV), whereas the post-treatment difference was only 4.83 ft lbs (group II - IV). For groups III and IV, the pre-treatment and post-treatment

Figure 22

Group Means on Occasion for Variable 6

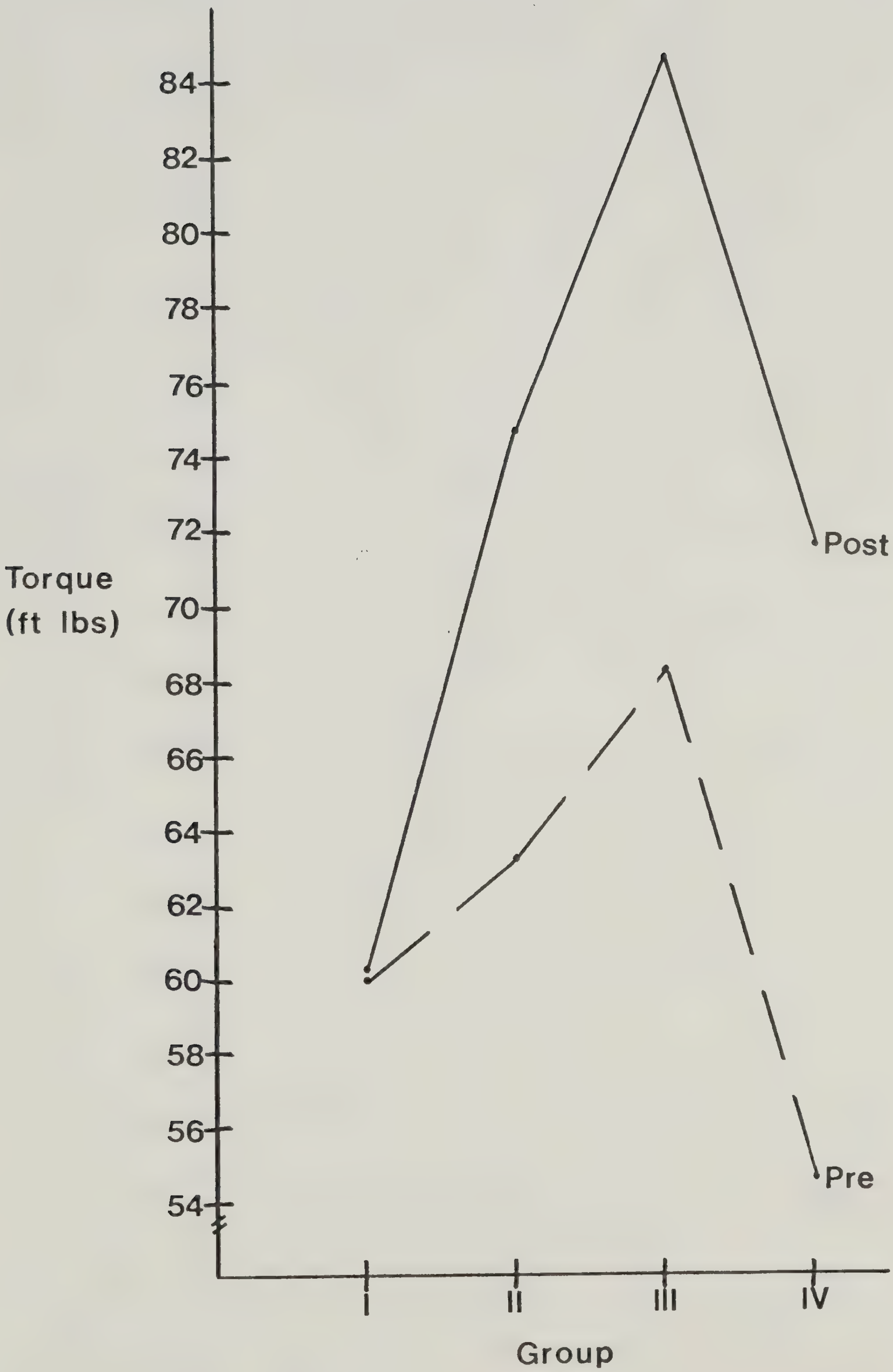
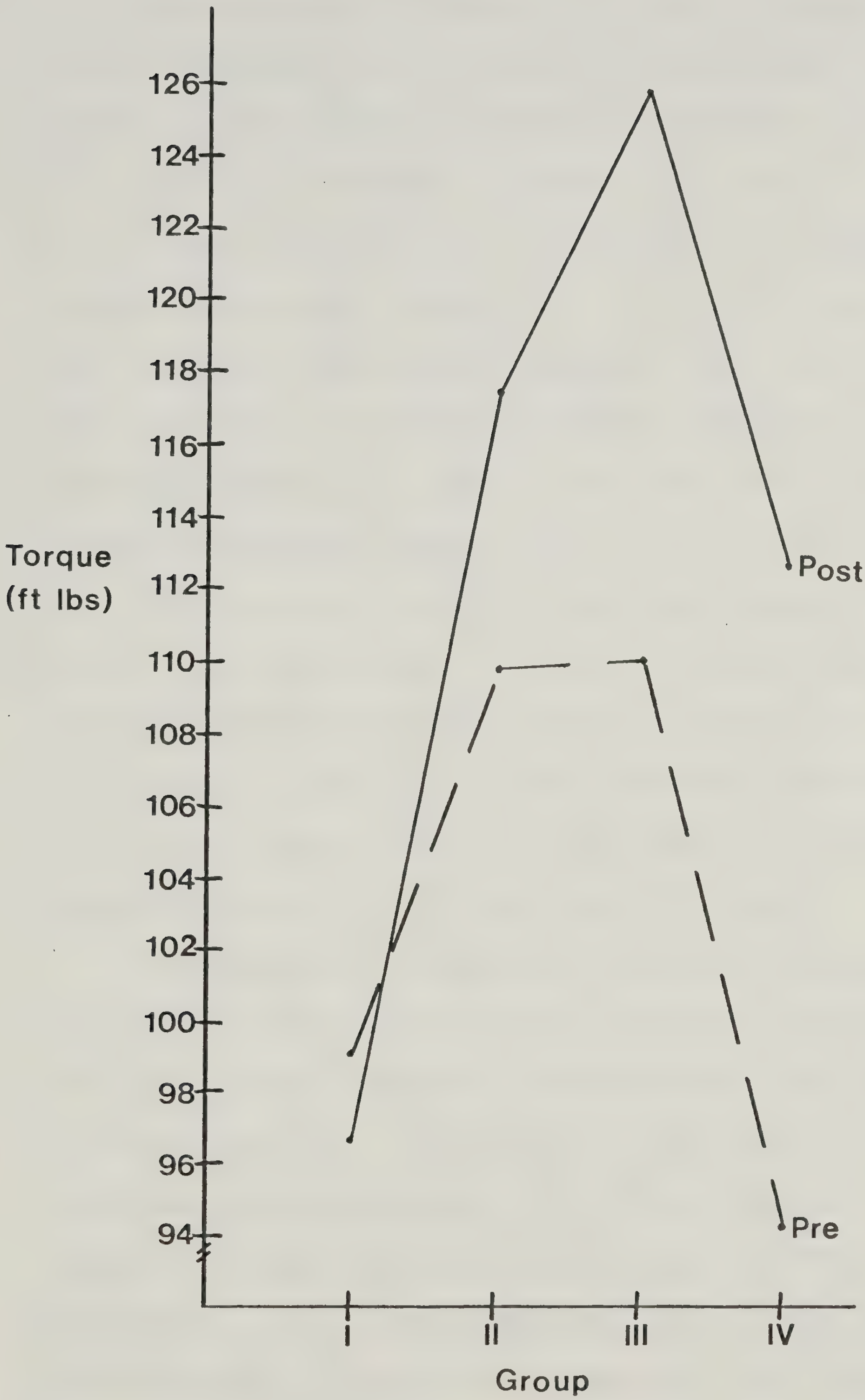


Figure 23

Group Means on Occasion for Variable 7



differences were similar (pre-treatment difference = 15.67 ft lbs; post-treatment difference = 13.16 ft lbs).

For variable 8 (Figure 24), group IV was observed to have the largest pre and post-treatment difference (16.34 ft lbs) with training. Group IV was also observed to have the lowest pre-treatment measure for groups II, III and IV. Groups I and IV were observed to have similar pre-treatment measures (group IV - I = 0.23 ft lbs) but the post-treatment difference increased to 14.57 ft lbs (group IV - I). Groups II and III differed on the pre-treatment measure by 2.58 ft lbs (group II - III) and on the post-treatment measure by 5.17 ft lbs (group II - III). For groups II and IV, the pre-treatment difference was 12.42 ft lbs (group II - IV), whereas the post-treatment difference was 4.83 ft lbs (group II - IV). For groups III and IV, the pre-treatment difference was 9.84 ft lbs (group III - IV), whereas the post-treatment difference was 0.34 ft lbs (group IV - III).

For variable 9 (Figure 25), group IV demonstrated the largest pre and post-treatment difference (23.83 ft lbs). Group IV was also observed to have the lowest pre-treatment measure. For groups II and III, the pre-treatment difference was 6.67 ft lbs (group II - III), whereas the post-treatment difference was 2.17 ft lbs (group III - II). For groups II and IV, the pre-treatment difference was 9.83 ft lbs (group II - IV), whereas the post-treatment difference was 12.00 ft lbs (group IV -

Figure 24

Group Means on Occasion for Variable 8

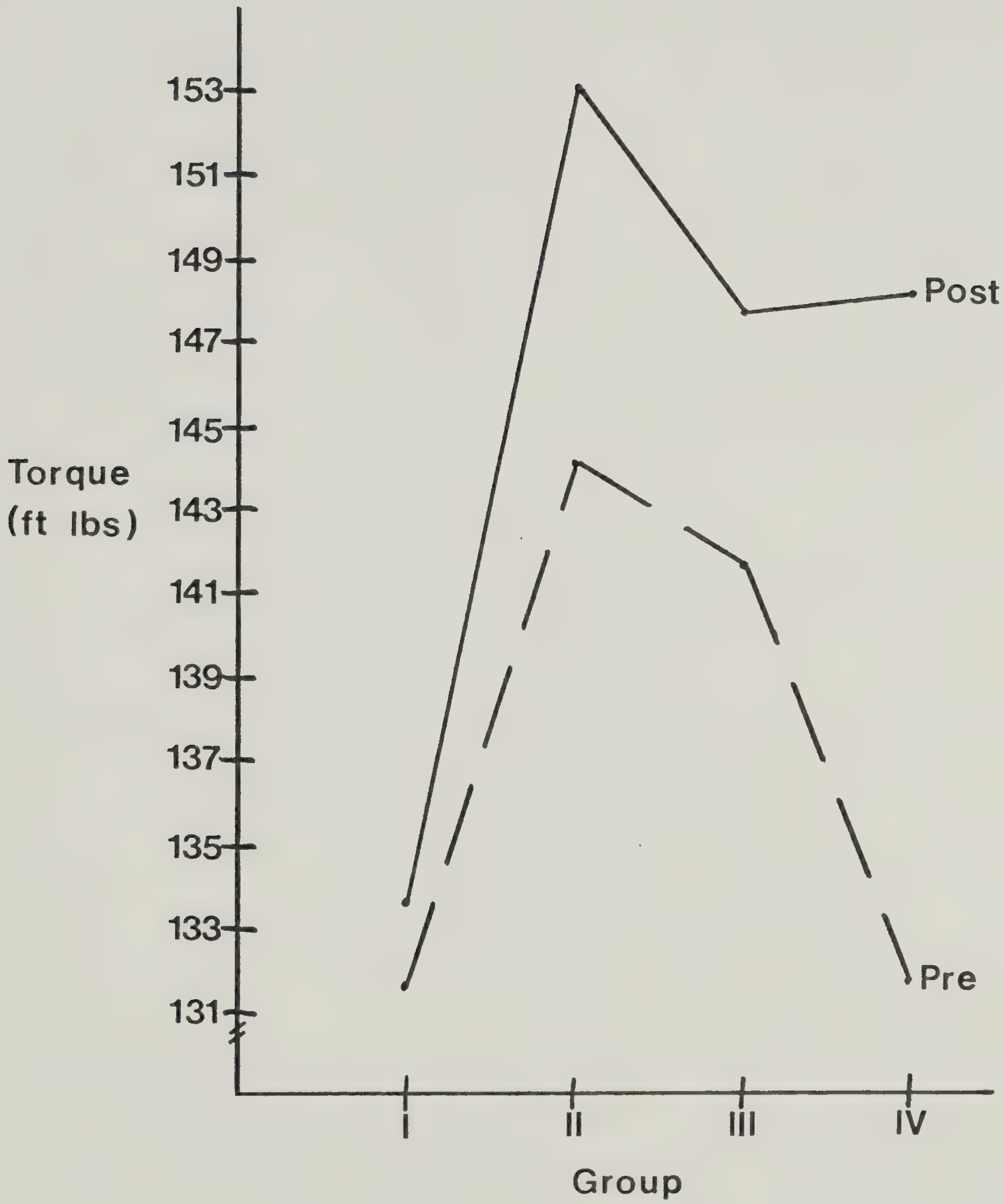
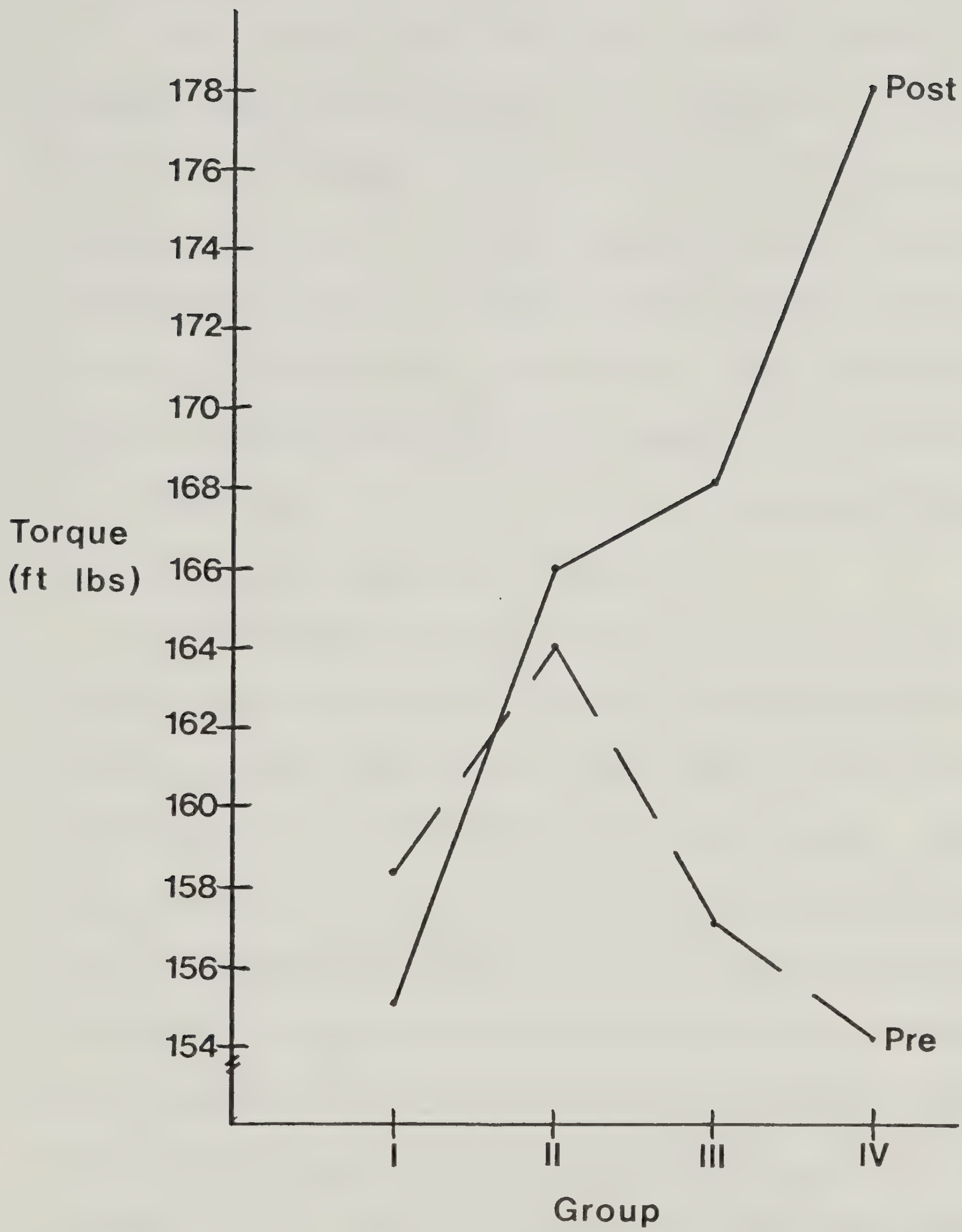


Figure 25

Group Means on Occasion for Variable 9



II). For groups III and IV, the pre-treatment difference was 3.16 ft lbs (group III - IV), whereas the post-treatment difference was 9.83 ft lbs (group IV - III).

Discussion

The overall results of the study support the previous findings by Currier et al. (8), Garrett et al. (13), Hartsell (21) and Massey et al. (39). EMS concurrent with isometric exercise improves quadriceps strength beyond performance levels of individuals who do not train. Additionally, individuals that train using isometric exercise increase quadriceps strength beyond performance levels for individuals who do not train, although significance varies for the nine variables.

The present study illustrated that overall, the use of EMS concurrent with isometric exercise was not significantly more effective in increasing quadriceps strength than training by isometric exercise alone. Garrett et al. (13) and Currier et al. (8) had concluded similar findings, whereas Taylor et al. (57) noted that subjects receiving EMS increased quadriceps strength beyond performance levels of subjects receiving exercise only. Godfrey et al. (15) supported the results of Taylor et al. (57). Johnson et al. (23) concluded that EMS was effective in improving quadriceps strength in patients with P-FC, but was of greatest benefit in combating the lost voluntary control of the quadriceps. The difficulty arises when

comparisons are attempted between previous studies, or previous studies and the present study. The status of muscular health of the subjects in all studies involving the use of EMS differs, and consequently all observations must be accepted and taken in light of individual circumstances. Ashcroft (1), and Johnson et al. (23) conclusively stated that the weaker the muscle, the greater were the strength gains after an EMS training program. Effectively, the results of the present study support the previous conclusion by Ashcroft (1), and Johnson et al. (23). The average pre-treatment measure for the group receiving bipolar EMS concurrent with isometric exercise was lower than the group receiving isometric exercise or the group receiving monopolar EMS concurrent with isometric exercise. Excluding the measurements for the variable of dynamic strength, the greatest pre to post-treatment differences were observed for the subjects receiving bipolar EMS concurrent with isometric exercise. Regarding the individual subject measurements for the groups having undergone training, the subjects in the EMS concurrent with isometric exercise groups consistently demonstrated that the lower the initial strength level, the greater was the improvement in quadriceps strength after training.

The two concepts that EMS concurrent with isometric exercise is more effective in increasing quadriceps strength than no training, and that EMS concurrent with isometric exercise may be more effective than isometric

exercise done for increasing quadriceps strength in weakened muscle are important. When the two concepts are combined with the reported physiological effects of EMS, which include increased motor unit recruitment, reduced reflex inhibition, increased capillary blood flow, improved oxygenation of the tissues, improved removal of metabolic waste build-up, and prevention of venous stasis (4,33,54), the importance for clinical use of EMS during rehabilitation becomes apparent.

Few studies in the literature have observed changes in muscle girth, after EMS training. Godfrey et al. (15) noted an increase in muscle bulk for injured muscle subjected to EMS training, and Johnson et al. (23) reported that the greater the initial muscular atrophy, the more significant were the girth increments after a program of EMS. Significant changes in girth were not observed in the present study, but the changes which did occur remain noteworthy. For girth at 77.5%, the observation was made that the greatest increments in girth occurred to the groups with the smaller initial girth measures. The EMS concurrent with isometric exercise groups were observed to have smaller pre-treatment girth measures than the isometric exercise group, and thus were also observed to have the greatest difference on occasion after training. For the EMS concurrent with isometric exercise groups only, the same finding was observed. A similar finding was observed for girth at 50.0%. The increment with training

for the bipolar EMS concurrent with isometric exercise group was the greatest of any of the girth differences for the groups which underwent training. The loss of girth at 50.0% for the subjects in the isometric exercise group and the monopolar EMS concurrent with isometric exercise group may be indicative of a loss of subcutaneous tissue (27).

The effects of the EMS techniques concurrent with isometric exercise on girth changes at 77.5% and 50.0% are worthy of note. For girth at 77.5% the monopolar EMS concurrent with isometric exercise group had an initial girth measurement of 1.49 cm greater than the bipolar EMS concurrent with isometric exercise group. The difference after training favored the monopolar EMS concurrent with isometric exercise group by 1.20 cm. Thus the changes were similar for the EMS concurrent with isometric exercise groups at 77.5%. However, at 50.0% the monopolar EMS concurrent with isometric exercise group had an initial girth measurement of 3.77 cm greater than the bipolar EMS concurrent with isometric exercise group, whereas the difference after training favored the monopolar EMS concurrent with isometric exercise group by 1.45 cm. Thus, the bipolar EMS technique concurrent with isometric exercise was more effective for increasing girth at 50.0% than the monopolar EMS technique concurrent with isometric exercise.

Physiologically, the cross-sectional area of a muscle increases with exercise as a result of increased myofibrillar density and a reduction in the amount of sarcoplasm

in the contractile complex (27). The subjects in the monopolar and bipolar EMS groups performed isometric exercise concurrent with EMS, and, since an EMS induced muscle contraction most closely approximates a voluntary contraction (55), similar rationale for girth increments with EMS concurrent with isometric exercise may be indicated. Concurrent with the physiological changes is an increased quality of contraction, which is dependent upon the number of contracting fibres, a reported EMS effect (27,35,54). The rationale for the nature of the girth changes may be related to the EMS technique used. Bipolar EMS produces a direct and even distribution of current between the two electrodes and throughout the vastus medialis muscle. As a result, the physiological changes of increased myofibrillar density and reduction of sarcoplasmic reticulum may occur throughout the course of the muscle, creating girth increments at 77.5% and 50.0%. Monopolar EMS produces an indirect stimulation to the quadriceps muscle group as a whole, and specifically focuses on the vastus medialis muscle through the motor point. As a result, the physiological changes associated with increased girth were specific to the higher intensity of stimulation given to the vastus medialis through the motor point. Thus, the girth increment at 77.5% and lack of increment at 50.0% may be explained for the monopolar EMS concurrent with isometric exercise group.

The different methods of training were observed to

have varying effects on dynamic strength, muscular power and muscular endurance. Post-treatment increments were observed for the training groups on all the isokinetic measures. Significant overall interaction effects were observed for the measures of muscular power and muscular endurance, but interaction effects between the training groups for the two previously mentioned measures were lacking. Regarding actual torque or time changes with training, the EMS concurrent with isometric exercise groups were generally observed to improve more. The improvements may be indicative of the lower initial levels of strength and also of the additional effects of EMS concurrent with isometric exercise and associated EMS physiological changes (4,21,40).

The changes in dynamic strength for the EMS concurrent with isometric exercise groups were contrary to expectation. For all groups taken simultaneously, a significant pre and post-treatment effect was observed, but further analysis did not produce a significant interaction effect between the groups. A possible explanation is that the majority of subjects in the control group had post-treatment measurements which were considerably greater than the corresponding pre-treatment measures. The subjects in the control group may have given an unusually higher effort on the first isokinetic measure since similar increments were not observed for the remaining measurements.

Greater effects of treatment were expected for the EMS groups for the following reasons:

1. Previous studies (30,43,52,64) reported either a maintenance of strength or strength increments after a program of isometric exercise. Other studies (12,23,27,35, 61) have reported increments in strength after an EMS program. Since a muscle contraction induced by EMS most closely approximates a voluntary effort, and the present study combined voluntary with involuntary effort, increments resulting from EMS concurrent with isometric exercise training should have been at least as great as the changes associated with exercise alone.

2. The isometric exercise group demonstrated a considerable increase after training. Thus, the EMS concurrent with isometric exercise groups were expected to demonstrate increments at least as great as the isometric exercise group since the only difference between the training groups was the EMS.

3. The literature (2,27) has reported a positive correlation between increments in muscle girth and strength gains. Although not significant, girth increments were observed for the EMS concurrent with isometric exercise groups in the present study.

4. Muscular power and muscular endurance improved with training for the EMS concurrent with isometric exercise groups. Thus, a subsequent increment for the dynamic strength measure was expected.

5. Kots (26,27) stated that optimal increments in strength occurred after 20 to 25 stimulation sessions. Subjects in the present study received a minimum of twenty-eight EMS sessions.

6. Kots (27) stated that EMS was capable of recruiting more motor units beyond that which an individual was capable of recruiting through a voluntary effort, towards enhancement of strength by 10% to 30%. Similar effects may result with the use of a low frequency stimulator.

Several viewpoints may be indicative of the performance by the EMS concurrent with isometric exercise groups. During the training sessions, the subjects in the EMS concurrent with isometric exercise groups were requested to withstand the maximal intensity of current barely tolerable, and concurrently give a maximal voluntary effort. Considering the sensory or skin irritation normally associated with low frequency faradic stimulators (34), the concept of maximal voluntary effort may have been masked. The idea of discomfort is different from that reported by Curwin et al. (9) who stated that subjects were not producing maximally as a consequence of pain resulting from a sensation of muscle cramping. Secondly, the subjects may have subconsciously concluded that they did not have to work as hard on occasion since the current would provide the little "extra effort" towards the contraction. Consequently the subjects became dependent on the current for help on the voluntary output.

The most plausible viewpoint is the latter. When the subjects in the EMS concurrent with isometric exercise groups attempted the first isokinetic post-treatment measure, which was dynamic strength, they relied on the help normally provided by the EMS current. Once the absence of the current was accepted, the subjects increased their voluntary effort to approach maximum, as illustrated by the post-treatment increments for measures of muscular power and muscular endurance. Conceivably, if the possibility of current dependency had not occurred, the change with training in dynamic strength for the EMS groups would have been at least as great as the changes observed for the isometric exercise group.

For the EMS concurrent with isometric exercise groups, the group training with monopolar stimulation may have the potential to improve dynamic strength more. Though the increments were small for the EMS concurrent with isometric exercise groups, the monopolar EMS concurrent with isometric exercise group improved more, even with a higher initial level of strength. Monopolar EMS affects the whole of the quadriceps group through indirect stimulation but intensely stimulates the vastus medialis through the motor point (4). The parameter of dynamic strength involves the whole of the quadriceps muscle group working as a harmonious unit, and does not rely on a single muscle for optimal performance. For example, the vastus medialis muscle working in isolation does not have

the ability to extend the lower limb (36,37) Thus, the suggestion that the monopolar technique affecting the whole of the quadriceps muscle group rather than the bipolar technique affecting the vastus medialis muscle for increasing dynamic strength is feasible.

Once the statistical analysis was completed, the interaction effects for the individual variables of muscular power and muscular endurance were the only significant individual variables. Although previous studies have not reported observations on muscular power and muscular endurance, several viewpoints may be stated in support of the present results. All the groups involved in training demonstrated improvements in muscular power, but the EMS concurrent with isometric exercise groups demonstrated the greatest changes with training. The monopolar EMS concurrent with isometric exercise group increased 11.26% and the bipolar EMS concurrent with isometric exercise group increased 15.78%. The increments in muscular power for the EMS concurrent with isometric exercise groups were significant when each EMS concurrent with isometric exercise group was compared to the control group. Although the isometric exercise group improved, the change with training was insufficient for significance over the control group. Thus, the EMS concurrent with isometric exercise groups were more effective than isometric exercise alone for improving muscular power, when compared to a group that did no training. Changes within the EMS

concurrent with isometric exercise groups were not enough to definitely conclude which EMS technique concurrent with isometric exercise is more effective in enhancing muscular power, which may be indicative of the limitations of a low frequency muscle stimulator used in the training of healthy muscle. Several viewpoints in support of the increments in muscular power for the EMS concurrent with isometric exercise groups are as follows:

1. The physiological effects of EMS include increased motor unit recruitment, improved peripheral nerve effects, and improved capillary blood flow (33,36), factors known to influence muscular power.

2. Kots (26,27) after studying muscle fibre types and rates of firing concluded that the most suitable frequency to cause maximal power of a muscle was a rhythmical stimulation of between 50 to 100 cps. For example, if the frequency was 100 cps, stimulation of only a fraction of the quickest muscle fibres would occur, and stimulation with a frequency of 30 cps would achieve a maximal contraction of the slowest muscle fibres but still induce tetany in the faster fibres (67). The muscle stimulator used in the present study had a frequency of 65 cps, capable of stimulating the fast twitch and slow twitch fibre types.

3. Optimal power increments were produced after a minimum of 10 to 15 stimulation sessions (27). The present study was in accordance with the findings of Kots.

4. Normally when a muscle contraction occurs with

the intensity of the contraction increasing slowly, the order of recruitment is from slow twitch fibres, innervated by small motoneurons, to fast twitch fibres, innervated by large motoneurons. According to Kots (27), the order of recruitment changes with a sudden strong change in electrical intensity, such as that provided by EMS, and the fast twitch fibres are recruited before the slow twitch fibres (27). Since power predominantly involves the action of fast twitch fibres (2), power increments after training with EMS are warranted. Kots (26,27) stated that although power may increase by increasing the percentage of fast twitch to slow twitch fibres, the rationale is more likely to be the result of the fast twitch and slow twitch fibre ratio remaining the same, but the quality of recruitment tends to be more specific towards activating fast twitch fibres.

5. Normally, a certain amount of CNS inhibition is present during a muscle contraction (2), and the subsequent recruitment of all motor units in a muscle or muscle group becomes impossible and thus dampens the eventual power output. A decrease in CNS inhibition would facilitate motor unit recruitment and enhance power (2). With the use of EMS, the CNS does not give input, but voluntary contraction increases, implying a change taking place in the peripheral nervous system (27). Thus, power increments are possible.

Considering the low initial measurements for the

bipolar EMS concurrent with isometric exercise group, on muscular power, a greater change due to training may have been expected. The potential for muscular power to improve more with the use of monopolar EMS concurrent with isometric exercise may be reasoned by the following:

1. Power should increase as more muscles are recruited, and as these muscles increase in strength. Monopolar EMS affects the whole of the quadriceps muscle group, not a single muscle, and the stimulation would provide for an increased recruitment of motor units causing an increase in neuromuscular facilitation, and finally an enhancement of power performance.

2. The subjects in the bipolar EMS concurrent with isometric exercise group may have reached the maximal intensity limit on the muscle stimulator, but still have been able to tolerate more. If a muscle is stimulated directly, the increase in contraction quality with increments in current intensity is less marked due to an increased excitation range (4). If a muscle is stimulated through its nerve, such as the monopolar technique, a slight increase in current will give a marked increase in contraction quality. Thus, the subjects in the monopolar EMS concurrent with isometric exercise group may not have reached the limit of maximal intensity on the stimulator.

Muscular endurance was the only other variable observed to demonstrate a significant change when group interactions were considered. Both techniques of EMS

concurrent with isometric exercise were observed to increase muscular endurance significantly over a group that did not train. The isometric exercise group did not significantly increase when compared to the control group. The difficulty arises in conclusively stating which EMS technique concurrent with isometric exercise is more effective in improving muscular endurance, for reasons similar to the reasons stated for muscular power. Considering the initial levels of performance and improvements with training, the bipolar EMS concurrent with isometric exercise group was observed to provide the greatest effects towards improving endurance. Several suggestions are given in support:

1. EMS increases capillary blood flow, improves oxygenation of tissues, improves removal of metabolic waste products, and increases motor unit recruitment (21,33,56). Muscular endurance during training has been shown to increase with improvements in the aforementioned factors. With the use of EMS, the improvements towards enhancement of muscular endurance should be at least as great as with exercise alone.

2. Bipolar stimulation specifically affects the vastus medialis muscle. As an individual performs the endurance parameter, fatigue occurs causing the lower limb to fail in reaching the last few degrees to full extension, of the knee. The last 30^{o} to full extension requires a 60^{o} increase in quadriceps force (36,37) without

fatigue. Vastus medialis works throughout the full range of motion to knee extension, but as a result of the fibre alignment and the low angle of insertion of the distal fibres, the angle of pull for vastus medialis is more efficient towards full extension than the remaining quadriceps muscles. Thus, specific stimulation of vastus medialis with the bipolar technique may enhance muscular endurance more than the monopolar EMS technique.

Effects of treatment on the isometric measures of performance are worthy of note, even though no significant interaction occurred. All training techniques were observed to increase mean torque at all angles of knee extension tested. A considerable increase with training occurred at -15° and -30° knee extension for all groups who participated in a training program at -30° knee extension. The final 30° to full extension is a biomechanically inefficient angle for the quadriceps muscle, since the muscles are in a shortened position. The ability to maintain or improve quadriceps strength in the final 30° to full extension by training at -30° knee extension is of clinical importance. The last 30° to full knee extension is a difficult range to regain after injury, surgery, or immobilization, and the traditional quadriceps lag is frequently observed. By maintaining or improving quadriceps strength in the difficult range of knee extension, the quadriceps lag may be reduced, an alteration of reflex inhibition due to peripheral nerve and CNS modification

may occur, and rehabilitation would be able to be started at a more advanced level, thus reducing the conventional rehabilitation time. The present findings which demonstrate an ability to maintain strength at weak angles for the quadriceps muscles, support earlier findings (21) which demonstrated that no decrement in strength was observed at -15° and -30° knee extension after four weeks of monopolar EMS concurrent with isometric exercise given to a healthy, casted lower limb. The monopolar EMS technique concurrent with isometric exercise may have the potential to be more effective in increasing isometric strength at the weak angles of knee extension since the initial level for the monopolar EMS concurrent with isometric exercise group was higher than for the bipolar EMS concurrent with isometric exercise group, but the change with training for the monopolar EMS concurrent with isometric exercise group approximated the change with training for the bipolar EMS concurrent with isometric exercise group.

The converse may be observed for the angles of -45° and -60° knee extension. Although the bipolar EMS concurrent with isometric exercise group had a lower initial strength level, the change with training was considerable and may be specific to the technique of stimulation.

Specificity of training was observed to exist. The angle of training was set at -30° knee extension for all groups except the control group.

Thus far, significant differences between the effects

of monopolar and bipolar EMS techniques concurrent with isometric exercise are lacking. Even so, suggestions for clinical use are still possible. If either EMS technique concurrent with isometric exercise has the potential to increase quadriceps strength in healthy, innervated muscle, the effects of EMS concurrent with isometric exercise on injured muscle and joints should be at least as great. The monopolar EMS technique concurrent with isometric exercise may be the technique to use most often for general improvement of quadriceps performance, the prime concern in rehabilitation. After the quadriceps muscles have reached an acceptable level of restoration of the functional components, focus of attention may be given to vastus medialis. Thus, the bipolar EMS technique concurrent with isometric exercise should be employed to enhance hypertrophy of vastus medialis for the role that the muscle plays in patellar re-alignment and increasing quadriceps strength at greater negative angles of knee extension.

However, if the underlying pathology was one of P-FC, patellar subluxation, or patellar dislocation, then the bipolar EMS technique concurrent with isometric exercise should be utilized throughout rehabilitation.

Although complete ramifications of EMS concurrent with isometric exercise, on healthy or injured muscle, remain unknown, studies such as the present one are slowly introducing new concepts and ideas which will lead to

further research in an attempt to aid in the rehabilitation of musculoskeletal trauma. Eventually we shall see a reduction in the time conventionally required to restore a limb to complete functional restoration of all the components.

CHAPTER V

SUMMARY, CONCLUSIONS, OBSERVATIONS AND RECOMMENDATIONS

Summary

The isometric exercise, monopolar EMS technique concurrent with isometric exercise, and bipolar EMS technique concurrent with isometric exercise were observed to enhance quadriceps strength over six weeks of training. Generally, the EMS techniques concurrent with isometric exercise were as effective as but no more effective than isometric exercise alone, for enhancing quadriceps strength.

Changes in girth measurements were observed to be related to the type of training provided. The EMS concurrent with isometric exercise groups were observed to increase girth at 77.5% as a result of the concentration of stimulation to vastus medialis. The bipolar EMS technique concurrent with isometric exercise increased the girth at 50.0% by 2 cm for the bipolar EMS concurrent with isometric exercise group; this resulted from the direct and even distribution of current throughout the vastus medialis muscle.

Dynamic strength was observed to improve for the isometric exercise group, but the increments for the EMS concurrent with isometric exercise groups were minimal. The subjects in the EMS concurrent with isometric exercise groups may have relied on the EMS current, and consequently reduced the maximal voluntary effort on the first

isokinetic measure of the post-test. The EMS concurrent with isometric exercise treatments were more effective for enhancing muscular power and muscular endurance. When differences in pre-treatment measures and rates of improvement were considered, the monopolar EMS concurrent with isometric exercise group demonstrated a greater improvement generally, but the bipolar EMS technique concurrent with isometric exercise was more effective in enhancing muscular endurance.

Few significant differences were observed for the isometric strength variables when the isometric exercise group was contrasted with either of the EMS concurrent with isometric exercise groups. Considering the pre-treatment measures and rates of change with training, monopolar EMS technique concurrent with isometric exercise was observed to be more effective towards improving isometric strength at the weak angles for the quadriceps muscles, namely -15° and -30° knee extension. The bipolar EMS technique concurrent with isometric exercise was observed to be more effective towards improving isometric strength at the stronger angles of the quadriceps muscles, namely -45° and -60° knee extension.

The isometric strength measure of -30° knee extension was observed to have the highest F-ratio of all the isometric strength measures. Thus, specificity of training was indicated.

Conclusions

The following conclusions were made as a result of the present study.

1. EMS concurrent with isometric exercise, and isometric exercise alone may enhance quadriceps strength.
2. No significant difference existed between the monopolar and bipolar EMS techniques, each given concurrently with isometric exercise.

Observations

Throughout the present study the following observations have been made.

1. The observation was made that the lower the pre-treatment torque measurements, the greater the treatment effects.
2. Monopolar EMS concurrent with isometric exercise may be more effective than bipolar EMS concurrent with isometric exercise towards increasing muscular power.
3. Bipolar EMS concurrent with isometric exercise may be more effective than monopolar EMS concurrent with isometric exercise in increasing muscular endurance.
4. Training at an angle of -30° knee extension was observed to produce considerable strength increments at the weak angles (-15° and -30° knee

extension) for the knee joint.

5. At the weak angles for the knee joint (-15° and -30° knee extension), the monopolar EMS technique concurrent with isometric exercise was observed to be more effective for increasing quadriceps strength.
6. At the stronger angles for the knee joint (-45° and -60° knee extension), the bipolar EMS technique concurrent with isometric exercise was observed to be more effective for increasing quadriceps strength.

Recommendations

1. A study, utilizing the same format as the present study, needs to be done using muscle stimulators of different frequencies so that the effects of different current frequencies on selected physiological parameters may be determined.
2. A study investigating the histochemical and biochemical effects of monopolar and bipolar EMS on normal muscle, needs to be done to determine the effects of different formats of EMS at the intramuscular level.
3. A study involving bipolar and monopolar EMS concurrent with isometric exercise at -30° knee extension, combined with an EMG analysis during stimulation, needs to be done to determine the

response of a muscle or muscle group.

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APPENDIX A

Consent Form

ELECTRICAL MUSCLE STIMULATION
RESEARCH INFORMATION AND
CONSENT FORM

- conducted by Heather Hartsell
Fall 1980

University of Alberta

PURPOSE

The purposes of the proposed study are to compare two different techniques of electrical muscle stimulation, to standard isometric exercise, to no training; all over a time period of six weeks. You will be asked to participate as a subject in only one of the four groups.

Comparisons will be made on selected physiological parameters.

PROCEDURE PRE and POST TRAINING

a) assessment of muscular strength, power, endurance, and isometric strength at selected angles of knee flexion; using the Cybex Isokinetic machine. All measurements will be taken on the right leg.
b) girth measurements of the right leg taken at two locations.
c) maintain a weekly activity sheet given to you.

TRAINING FORMAT

a) Control group: required to attend the pre and post testing sessions and required to maintain a weekly activity sheet.
b) Isometric and Electrical Stimulation groups: all training will be performed daily, five days each week, for a period of six weeks. Training consists of fifteen minutes per day. Subjects will be required to maintain a weekly activity sheet.

The data and information obtained from the study will be used for scholarly publication and discussion. All data shall remain confidential and names will not be used to identify the subjects.

The personal data will be freely available to the subjects in the study upon completion of the project.

The procedure is entirely safe and not injurious in any way. All handling of the research equipment shall be by the researcher only.

The researcher agrees to answer any questions that the subjects may have concerning the procedures, or any other aspects of the study.

The subjects are free to withdraw consent and discontinue participation in the study at any time, and without prejudice.

CONSENT

I have read the description of the proposed research and understand its potential value. I am also aware that I am free to withdraw from participating at any time.

Signed:____________________

Date:____________________

APPENDIX B

Weekly Activity Sheet

E.M.S. RESEARCH

NAME: ______________________________

GROUP: I II III IV

ACTIVITY PERIOD: ______________ to ______________

Activity	#Sessions/Wk. or Distance/Wk.	Est. Total Time/Wk.	Avg. Intensity Lo / Med / Hi
Badminton			
Baseball			
Basketball			
Cycling			
Dancing			
Football			
Golf			
Gymnastics			
Handball- individual team			
Hockey- floor ice			
Jogging			
Orienteering			
Racquetball			
Rugby			
Skiing- cross-country downhill			
Soccer			
Sprinting			
Squash			
Stair Running			
Swimming			
Tennis			
Volleyball			
Walking			
Weightlifting			
Wrestling			
Other (specify)			

APPENDIX C

Data Sheet for Testing

DATA SHEET

SUBJECT: ______________________________

BIRTHDATE: ______________________________

WEIGHT: ______________________________

GROUP I II III IV

	Pre-Treatment ( )	Post-Treatment ( )

a) Girth

ASIS -- MJL = _____cm

1. 77.5% = _____cm ______________

2. 50.0% = _____cm ______________

b) Cybex II (# holes showing __________)

1. Dynamic Strength (30^o/sec) ______________

2. Power (180^o/sec) ______________

3. Endurance (180^o/sec)
   = 50% peak torque strength
   decrement ______________

4. Isometric Strength (0^o/sec)
   (knee extension)

   -15^o ______________

   -30^o ______________

   -45^o ______________

   -60^o ______________

APPENDIX D

Muscle Stimulation Data Sheet

E.M.S. DATA

NAME: ____

GROUP: Monopolar __________ Bipolar __________

Session	Date	mA Intensity Start	Finish
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
15			
16			
17			
18			
19			
20			
21			
22			
23			
24			
25			
26			
27			
28			
29			
30			

APPENDIX E

Terminology for

Statistical Data

Terminology
for Statistical Data

Variable 1: Girth at 77.5% (cm)
Variable 2: Girth at 50.0% (cm)
Variable 3: Dynamic Strength (ft lbs)
Variable 4: Muscular Power (ft lbs)
Variable 5: Muscular Endurance (sec)
Variable 6: Isometric Strength -15^{o} (ft lbs)
Variable 7: Isometric Strength -30^{o} (ft lbs)
Variable 8: Isometric Strength -45^{o} (ft lbs)
Variable 9: Isometric Strength -60^{o} (ft lbs)

APPENDIX F

Means for Groups x Variable on Occasion

and

Treatment Mean Differences on Occasion

For Groups x Variable

Table 1

Treatment Means for Groups x Variable

	Variable 1		Variable 2		Variable 3		Variable 4		Variable 5	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Group I n=5	39.54	39.98	51.54	51.78	159.60	168.80	95.40	97.60	35.10	35.66
	(s=0.56)		(s=0.50)		(s=1.01)		(s=0.75)		(s=0.58)	
Group II n=4	42.18	42.15	56.53	55.85	176.00	187.25	104.50	110.25	31.95	35.15
	(s=0.62)		(s=1.05)		(s=0.70)		(s=0.54)		(s=1.64)	
Group III n=6	41.17	41.80	53.97	53.77	171.33	176.33	96.17	107.00	35.55	39.63
	(s=1.17)		(s=0.56)		(s=0.64)		(s=0.32)		(s=2.66)	
Group IV n=6	39.68	40.60	50.20	52.32	163.67	164.83	84.50	97.83	36.03	41.43
	(s=0.88)		(s=3.00)		(s=0.81)		(s=0.20)		(s=1.93)	

Table 1 (cont'd)

	Variable 6		Variable 7		Variable 8		Variable 9	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Group I n=5	60.00	60.20	99.20	96.60	131.60	133.60	158.40	155.20
	(s=0.14)		(s=0.51)		(s=0.45)		(s=0.57)	
Group II n=4	63.25	74.75	109.75	117.50	144.25	153.00	164.00	166.00
	(s=1.07)		(s=0.88)		(s=0.94)		(s=0.45)	
Group III n=6	68.33	84.67	110.00	125.83	141.67	147.83	157.33	168.17
	(s=1.28)		(s=1.26)		(s=0.79)		(s=1.04)	
Group IV n=6	54.67	71.67	94.33	112.67	131.83	148.17	154.17	178.00
	(s=1.30)		(s=1.35)		(s=1.28)		(s=1.54)	

Table 2

Treatment Mean Differences on Occasion

For Groups x Variable

Variable

	1	2	3	4	5	6	7	8	9
Group I	0.44	0.24	9.20	2.20	0.56	0.20	-2.60	2.00	-3.20
Group II	-0.03	-0.68	11.25	5.75	3.20	11.50	7.75	8.75	2.00
Group III	0.63	-0.20	5.00	10.83	4.08	16.34	15.83	6.16	10.84
Group IV	0.92	2.12	1.16	13.33	5.40	17.00	18.34	16.34	23.83

APPENDIX G

Results of the Two-Way MANOVA
With Repeated Measures on Group Differences
For Variables 1 to 5 and 6 to 9
Taken Simultaneously

Table 3

Mean Group Effects Averaged

Over Occasion for Variables

1 to 5

	Variable					
Group	1	2	3	4	5	*p
I	39.76	51.66	164.20	96.50	35.38	
II	42.16	56.19	181.63	107.38	33.55	<.01
III	41.48	53.87	173.83	101.58	37.59	
IV	40.14	51.26	164.25	91.17	38.73	

$p \leq .05$

* $F = 9.82$

$df = 15, 44.6$

critical $F = 1.90$ (interpolated)

Table 4

Mean Group Effects Averaged

Over Occasion for Variables

6 to 9

	Variable				
Group	6	7	8	9	*p
I	60.10	97.90	132.60	156.80	
II	69.00	113.63	148.63	165.00	<.01
III	76.50	117.92	144.75	162.75	
IV	63.17	103.50	140.00	166.08	

$p \leq .05$

* $F = 2.95$

$df = 12, 45.3$

critical $F = 1.98$ (interpolated)

Table 5

Mean Occasion Effects Averaged

Over Groups for Variables

1 to 5

Occasion	Variable 1	2	3	4	5	*p
Pre-Treatment	40.64	53.06	167.65	95.14	34.66	<.01
Post-Treatment	41.13	53.43	174.30	103.17	37.97	

$p \leq .05$

* $F = 10.85$

$df = 5, 16$

critical $F = 2.85$

Table 6

Mean Occasion Effects Averaged

Over Groups for Variables

6 to 9

	Variable				
Occasion	6	7	8	9	*p
Pre-Treatment	61.56	103.32	137.34	158.48	
					0.03
Post-Treatment	72.82	113.15	145.65	166.84	

$p \leq .05$

* $F = 3.34$

$df = 4, 17$

critical $F = 2.96$

Table 7

Probabilities for

Helmert Contrast and Pair-wise Contrast

for Variables 1 to 5

Group	I	II	III	IV	*Helmert
I	-	<.01	<.01	<.01	<.01
II		-	<.01	<.01	<.01
III			-	<.01	<.01
IV				-	

$p \leq .05$

* Helmert contrast is group n versus the average of the remaining n-1 groups.

Table 8

Helmert Contrast and Pair-wise Contrast

for Variables 6 to 9

Group	I	II	III	IV	*Helmert
I	-	<.01	<.01	>.05	0.02
II		-	>.05	0.05	>.05
III			-	<.01	<.01
IV				-	

$p \leq .05$

*Helmert contrast is group n versus the average of the remaining n-1 groups.

APPENDIX H

Results of the Two-Way MANOVA
with Repeated Measures
on Group Differences
for Individual Variables

Table 9

Mean Group Effects and

Mean Occasion Effects

for Individual Variables

	*Mean Group Effect		**Mean Occasion Effect	
Variable	F	p	F	p
1	26.63	<.01	6.78	0.02
2	22.55	<.01	1.11	>.05
3	16.11	<.01	9.49	<.01
4	21.61	<.01	34.60	<.01
5	14.35	<.01	34.61	<.01
6	0.75	>.05	2.19	>.05
7	10.30	<.01	13.58	<.01
8	5.77	0.02	9.90	<.01
9	1.39	>.05	7.50	0.01

p ≤.05

* df = 3, 20

critical F = 3.10

** df = 1, 20

critical F = 4.35

Table 10

Helmert Contrast and Pair-wise Contrast

for Variable 1

Group	I	II	III	IV	*Helmert
I	-	<.01	<.01	>.05	<.01
II		-	0.04	<.01	<.01
III			-	<.01	<.01
IV				-	

$p \leq .05$

*Helmert contrast is group n versus the average of the remaining n-1 groups.

Table 11

Helmert Contrast and Pair-wise Contrast for Variable 2

Group	I	II	III	IV	*Helmert
I	-	<.01	<.01	>.05	<.01
II		-	<.01	<.01	<.01
III			-	<.01	<.01
IV				-	

$p \leq .05$

*Helmert contrast is group n versus the average of the remaining n-1 groups.

Table 12

Helmert Contrast and Pair-wise Contrast

for Variable 3

Group	I	II	III	IV	*Helmert
I	-	$<.01$	$<.01$	$>.05$	$<.01$
II		-	0.01	$<.01$	$<.01$
III			-	$<.01$	$<.01$
IV				-	

$p \leq .05$

*Helmert contrast is group n versus the average of the remaining n-1 groups.

Table 13

Helmert Contrast and Pair-wise Contrast

for Variable 4

Group	I	II	III	IV	*Helmert
I	-	$<.01$	0.02	0.02	$>.05$
II		-	0.01	$<.01$	$<.01$
III			-	$<.01$	$<.01$
IV				-	

$p \leq .05$

*Helmert contrast is group n versus the average of the remaining n-1 groups.

Table 14

Helmert Contrast and Pair-wise Contrast

for Variable 5

Group	I	II	III	IV	*Helmert
I	-	>.05	0.01	<.01	>.05
II		-	<.01	<.01	<.01
III			-	>.05	>.05
IV				-	

$p \leq .05$

*Helmert contrast is group n versus the average of the remaining n-1 groups.

Table 15

Helmert Contrast and Pair-wise Contrast

for Variable 6

Group	I	II	III	IV	*Helmert
I	-	>.05	>.05	>.05	>.05
II		-	>.05	>.05	>.05
III			-	>.05	>.05
IV				-	

$p \leq .05$

*Helmert contrast is group n versus the average of the remaining n-1 groups.

Table 16

Helmert Contrast and Pair-wise Contrast

for Variable 7

Group	I	II	III	IV	*Helmert
I	-	$<.01$	$<.01$	$>.05$	$<.01$
II		-	$>.05$	0.03	$>.05$
III			-	$<.01$	$<.01$
IV				-	

$p \leq .05$

*Helmert contrast is group n versus the average of the remaining n-1 groups.

Table 17

Helmert Contrast and Pair-wise Contrast

for Variable 8

Group	I	II	III	IV	*Helmert
I	-	$<.01$	$<.01$	$>.05$	$<.01$
II		-	$>.05$	0.04	$>.05$
III			-	$>.05$	$>.05$
IV				-	

$p \leq .05$

*Helmert contrast is group n versus the average of the remaining n-1 groups.

Table 18

Helmert Contrast and Pair-wise Contrast

for Variable 9

Group	I	II	III	IV	*Helmert
I	-	>.05	>.05	>.05	>.05
II		-	>.05	>.05	>.05
III			-	>.05	>.05
IV				-	

$p \leq .05$

*Helmert contrast is group n versus the average of the remaining n-1 groups.

APPENDIX I

MANOVA Interaction Effects
For Variables 1 to 5 and 6 to 9
Taken Simultaneously

Table 19

Interaction Effects

for Variables 1 to 5

Group	Interaction Effect p	*F-ratio
All groups	0.03	2.11
I vs II	>.05	1.10
I vs III	>.05	0.96
I vs IV	<.01	5.45
II vs III	>.05	0.98
II vs IV	0.03	3.50
III vs IV	<.01	7.70

$p \leq .05$

* All groups

df = 15, 39

criticial F = 1.93 (interpolated)

* Pairs of groups

df = 5, 14

critical F = 2.96

Table 20

Interaction Effects

for Variables 6 to 9

Group	Interaction Effect p	*F-ratio
All groups	>.05	0.71
I vs II	>.05	0.25
I vs III	>.05	0.58
I vs IV	>.05	0.75
II vs III	>.05	0.90
II vs IV	>.05	1.29
III vs IV	>.05	0.83

$p \leq .05$

* All groups

df = 12, 40

critical F = 2.00

* Pairs of groups

df = 4, 15

critical F = 3.06

APPENDIX J

Interaction Effects on

Individual Variables

1 to 5

Table 21

Interaction Effects on

Individual Variables

1 to 5

Variable	Group	Interaction Effect p	*F-ratio
1	All groups	>.05	0.80
2	All groups	>.05	2.29
3	All groups	>.05	1.30
4	All groups	0.01	4.74
	I vs II	>.05	0.99
	I vs III	0.02	7.20
	I vs IV	<.01	11.98
	II vs III	>.05	2.20
	II vs IV	0.04	4.89
	III vs IV	>.05	0.66
5	All groups	0.01	4.94
	I vs II	>.05	3.41
	I vs III	0.01	7.46
	I vs IV	<.01	14.08
	II vs III	>.05	0.41
	II vs IV	>.05	2.56
	III vs IV	>.05	1.15

$p \leq .05$

*All groups

df = 3, 17

critical F = 3.20

*Pairs of groups

df = 1, 17

critical F = 4.45